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ORIGINAL ARTICLES

INVESTIGATIONS ON THE COLD STORAGE OF MANGOES*

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(Received for publication on 31 December 1937)

(With Plates XI to XV and six text-figures)

THE mango is the premier fruit of tropical countries. It is greatly valued for its sweet taste and pleasant flavour. India possesses a virtual monopoly of mangoes of good quality. There are innumerable varieties grown in India. The Alphonso from Bombay, the Langra or Malda from Bihar and Uttar Pradesh, and the Peter from Madras are some of the well-known varieties in India. The production of these fruits is rapidly increasing. Efforts have been made during the recent years to regulate the home market and to find new markets in foreign countries. The fruit season is very short. The time of harvest varies in different localities. The Madras fruit comes to the market early in April, while fruit from the northern parts of India matures from July onwards, the Bombay season being at its height in May and June. The fruit is usually very perishable. The prices vary greatly according to the supply of the fruit in the market. At present, there are no means of holding over a surplus supply which can be put in the market at the time of scarcity. The fruit has got to be marketed at any price in order to avoid total loss. If, however, the supply could be regulated and the marketable 'life' of the fruit extended by the application of the cold storage methods, the problem of marketing mango, both in India and abroad, would be greatly simplified, as a regular and controlled supply is a pre-requisite to profitable marketing.

Some preliminary work on the storage of mango has been reported by Cheema and Gandhi [1926]. The authors used one of the storage chambers in the Crawford Market, Bombay, for their experiment in 1926. They found that the fruit of the Alphonso variety of mango could be preserved at 36°F. to 40°F. for about a month in a satisfactory condition. Joshi and Rama Iyer [1929], observed that ripe mangoes could be kept in a cold store for about three weeks but that unripe fruits stored in the same condition did not ripen afterwards when removed to higher temperatures.

Banerjee, Karmakar and Row [1934] started investigations on the cold storage of mango in 1930 at the Indian Institute of Science, Bangalore. They obtained the different temperatures by keeping incubators of the ordinary 'Hearson' type in a cold room (—2°C.) and controlling the temperature by the use of a mercuric thermo-regulator in place of the ordinary capsule. They observed that mature fruit ripened slowly at low temperatures and required about twenty to twenty-five days for ripening at 10°C. They further observed that pre-storage treatments, such as washing with antiseptic solutions, did not help in prolonging the storage life of the fruit and retarding its decay.

*The article, was originally published as a miscellaneous Bulletin No. 21 of the Council in 1939, being the results of the investigations of the Cold Storage Research Scheme, Kirkee, sponsored by the Council.

Cheema and Dani [1934] sent experimental consignments of mangoes to England in 1932 and 1933. The fruit crates were carried to London on board the P. and O. mail steamer in the Purser's cool room where the temperature varied, but was usually between 36°F. and 45°F. Some of the fruit reached the London market in good condition. They have published a report on the results of these experimental trials, but full information in regard to the cold storage transport of mango was not available.

Besides India, mango is now grown in the West Indies, Java, the Philippine Islands and in parts of the continents of America and Africa. Efforts are being made to transport this fruit from these countries to Europe. As early as in 1897, the No. 11 variety of mango was sent from Jamaica to London and this arrived after a voyage of twenty-one days in fine condition without the aid of the cool chamber [Wardlaw and Leonard, 1936]. Higgins [1906] reports certain experiments on the cold storage of mangoes at 34°F. and 40°F. He found that the fruits could be kept in good condition for thirty-one days. Cousins [1911] states that in 1909 mangoes were being sent from Jamaica to London, apparently with satisfactory results. Attempts at mango transport from Java to Holland are described by Spoon [1931], the fruits being packed in coconut fibre and held at 3°C. during the voyage of five to six weeks. Higgins and Punzalan [1925] conducted some experiments on the refrigeration of Philippine mangoes for the purpose of determining the right temperature of storage for export. They found that when mangoes were kept at 36°F. the friuts remained without injury for eighteen or more days but not over thirty-five days. Wardlaw and Leonard [1936] have published the results of storage trials of West Indian mangoes. They found that mangoes are subject to a low temperature injury if exposed to temperatures below 48°F. They have recommended a transport temperature of 48°F. to 50°F. during a voyage of fifteen to twenty days.

Besides storage temperature, it is observed that other important factors essential for the sound development of export trade in mango are :

(i) The selection of suitable varieties for storage.

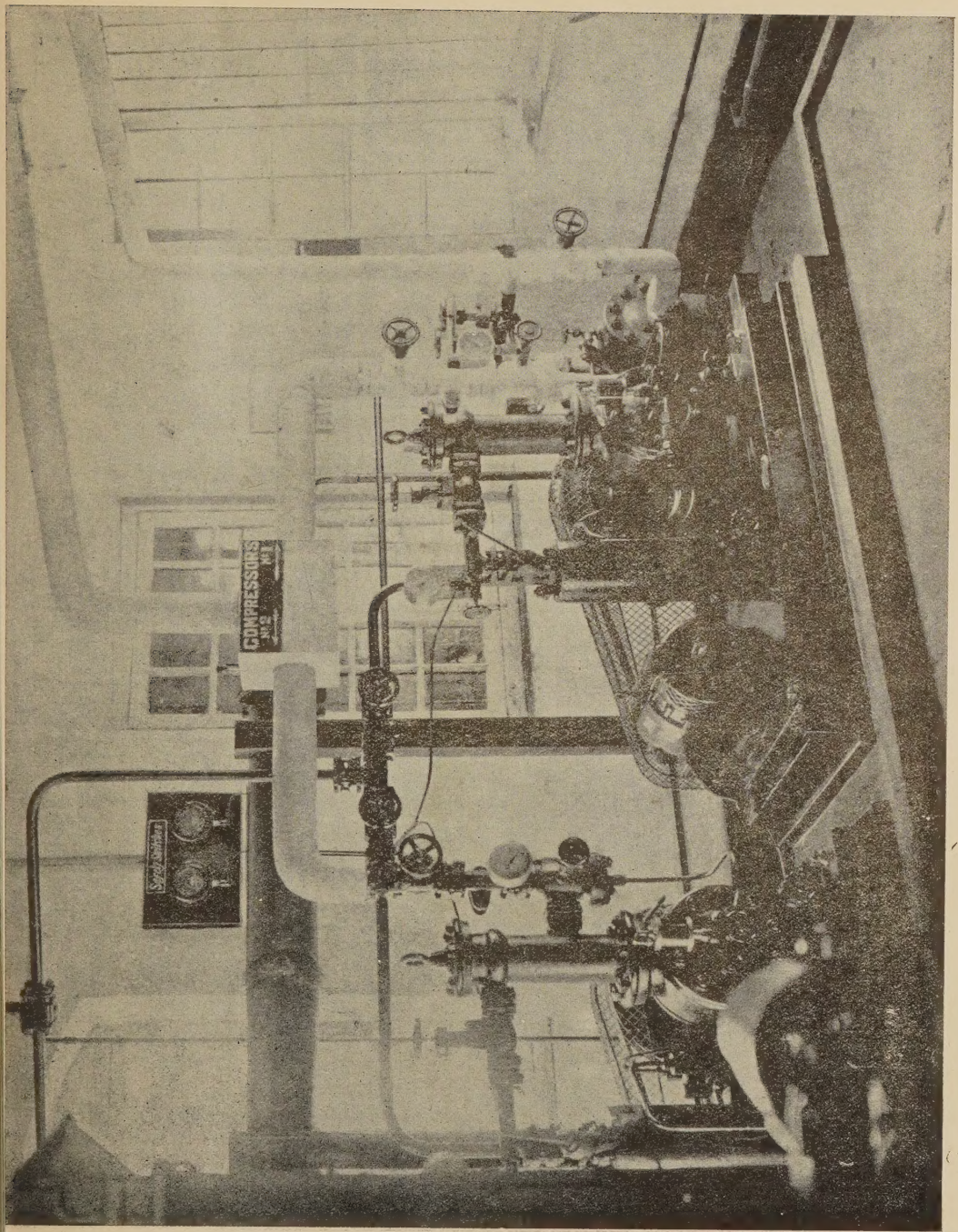
(ii) The correct stage of maturity at which the fruit is stored.

(iii) The proper methods of packing and packing material for storage.

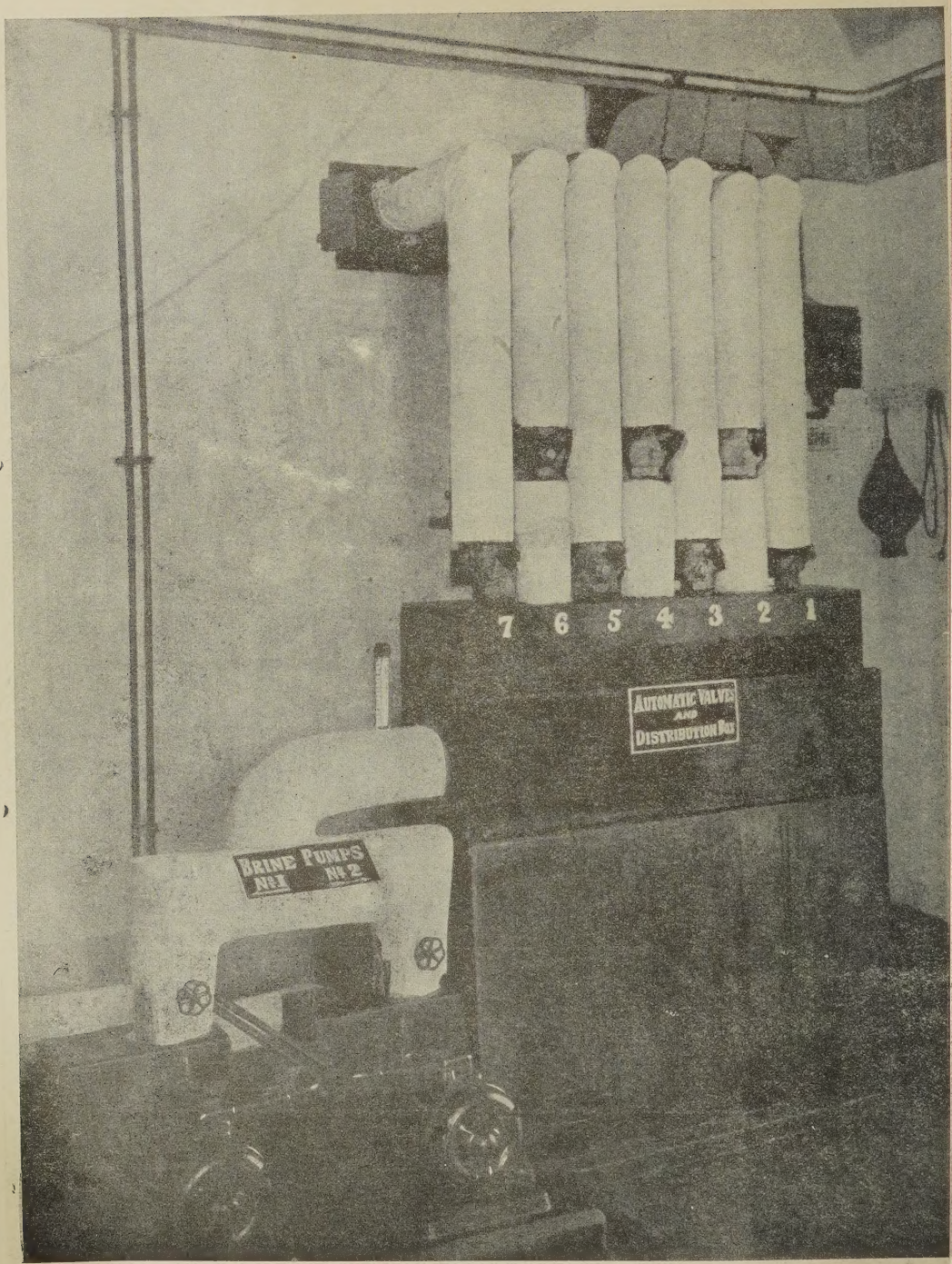
The Imperial (Now Indian) Council of Agricultural Research, realizing the importance of mango trade, sanctioned the Cold Storage Research Scheme for investigating thoroughly all the problems relating to the storage of mango. The present paper deals with the results of the investigations carried out during the first three years.

Cold storage chambers

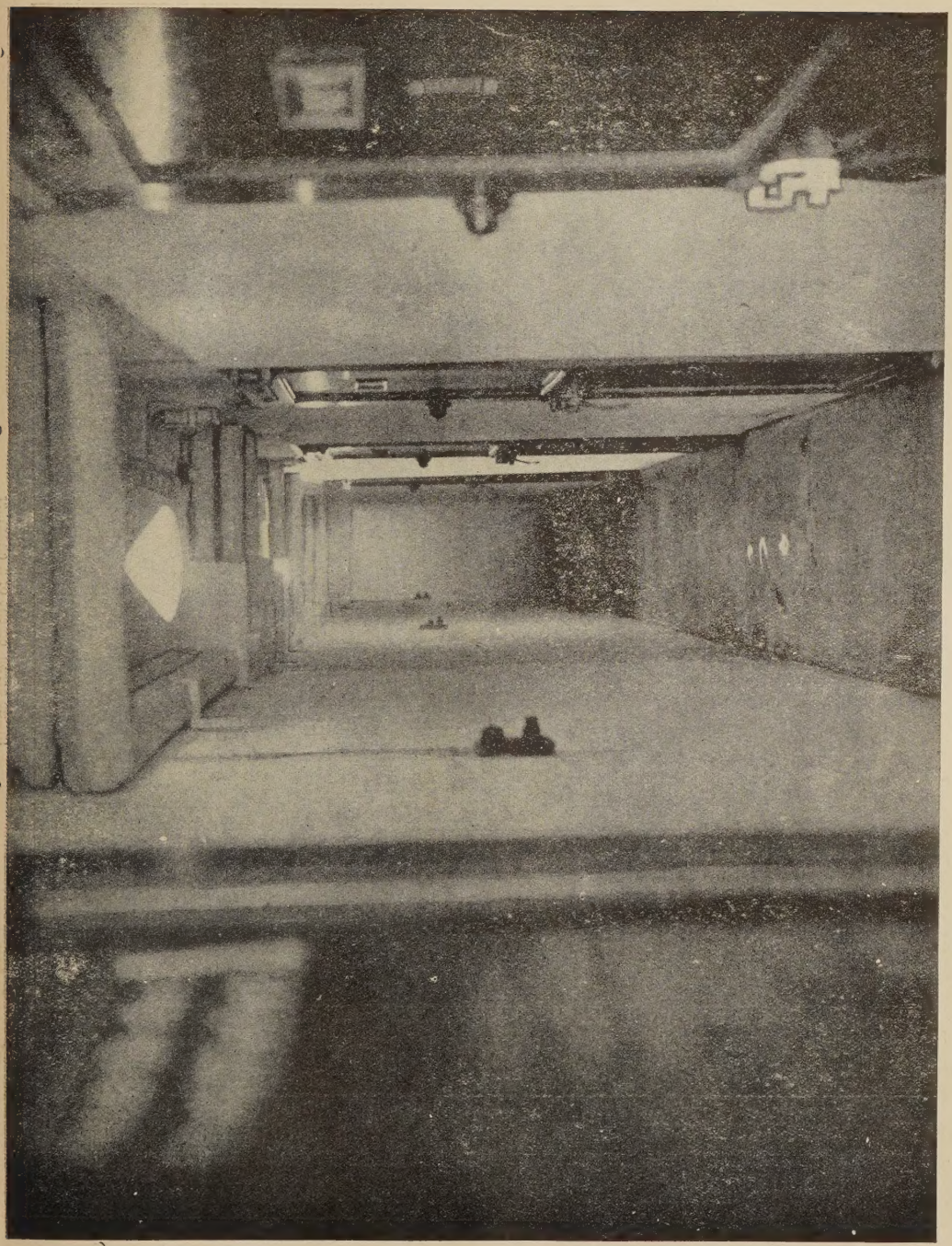
The cold storage plant was specially erected for these investigations at the Ganeshkhind Fruit Experiment Station, Kirkee, in 1934. The refrigerating machinery was supplied by Messrs. J. & E. Hall, Ltd. of Dartford, Kent, England, and the construction work was supervised by the Agricultural Engineer to the Government of Bombay.



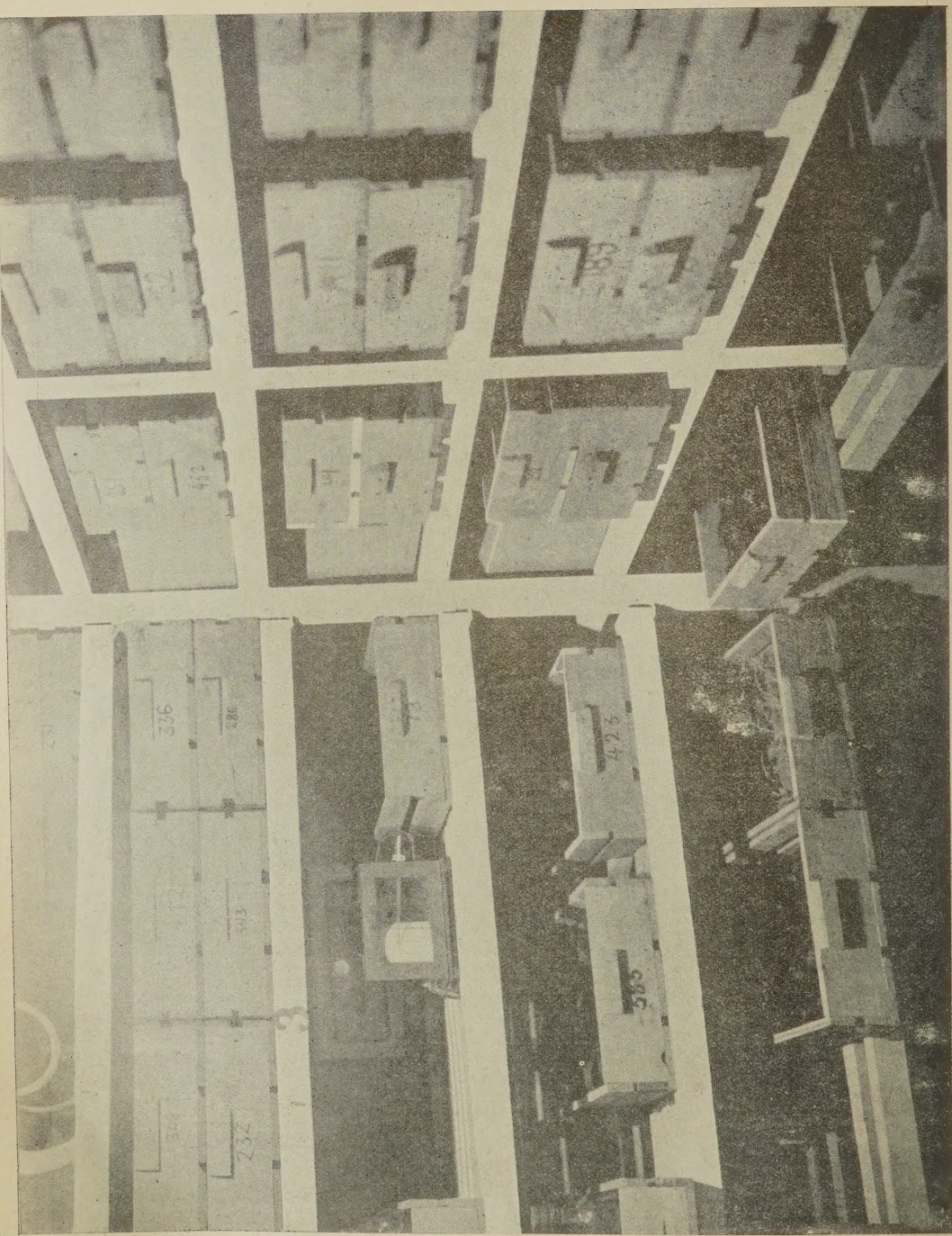
Ammonia compressors



Brine distribution box



Air-lock corridor and chambers



Inside arrangement of a chamber

The refrigerating plant consists of an ammonia compressor (5 H. P.) which is run by electric power (Plate XI). The evaporator coils cool down the brine which is circulated in the different chambers (Plate XII).

There are seven chambers, each 10ft. × 9ft. × 8ft., and in addition, there is a sufficiently wide (3ft.) air-lock corridor in front of the chambers (Plate XIII). Cork slab has been used as the insulating material in the construction of the walls, the floor and the ceiling of the cold chambers. Each chamber is fitted with an electrical fan (1 H. P.) of the propeller type for circulation of air in the chamber. A thermograph is placed in each chamber to record temperatures on a weekly chart. Suitable wooden racks, 2 ft. wide and of a total running length of 90 ft., have been fitted in each chamber for keeping the trays and boxes of fruit for the experiments. 'Daylight' electric lights have been placed in each chamber so as to get a better idea of the colour of the fruit (Plate XIV).

The whole plant is fully automatic. Each chamber is fitted with a thermostatic switch which automatically turns on the brine circulation and with it the fan for the circulation of air in the chamber when the temperature of the chamber gets higher than the regulated temperature. The brine circulation and the fan are automatically turned off when the regulated temperature is attained. The brine temperature is also automatically controlled. The compressor starts working as soon as the temperature of the brine rises above the regulated range and it stops when the brine is cooled down to the required temperature. A stand-by compressor and a brine pump have been provided in order to prevent any stoppages. The arrangement of the refrigerating machinery and the cold chambers is shown in Plates XI-XIV.

Plan of work

Range of temperatures

The seven chambers were first regulated at the temperatures 30°, 35°, 40°, 45°, 52°, 60° and 68°F. The chambers at 60°F. and 30°F. were changed to 48°F. and 43°F. respectively when intermediate temperatures between 45°F. and 52°F., and 40°F. and 45°F. were required for tests. The museum hall which is just by the side of these chambers was used for experiments at room temperature. The fruit was kept in a cupboard made with glass sides with arrangement for ventilation. The temperature in this cupboard varied usually from 80°F. to 96°F. during the course of the storage trials of mango.

The thermo-regulators were so set that the difference between the maximum and the minimum temperatures recorded every week on the thermographs was usually not more than +1°F. or —1°F. of the regulated temperature. The temperature in each chamber was quite uniform as tested at intervals by a thermometer placed at different positions in the chamber.

Relative humidity in the chambers

The relative humidity of a cold store is always one of the most important factors in the successful storage of fresh fruit. It has been observed that usually a relative humidity between eighty and ninety per cent gives the best results. During these

investigations the humidity of the chambers was found to be within this range as tested by a dry and wet-bulb thermometer.

Amount of carbon dioxide in the atmosphere of the chambers

Special care was taken to prevent accumulation of the carbon dioxide produced by the respiration of the fruit under observation in the chambers. The amount of carbon dioxide present in each chamber was determined from time to time. The amount of the gas present in the chambers was never allowed to exceed one per cent. Frequent opening of the chambers for inspection work did not allow the gas to accumulate.

Supply of mangoes for the storage experiments

The mangoes used in these investigations were of the following twenty-eight different varieties obtained from different provinces. These varieties were selected with the help of the Agricultural Departments of the different provinces and they represent some of the well-known types of mango grown in India :

(*a*) The Madras Presidency :

(1) Peter ; (2) Suwarnarekha ; (3) Banganpalli ; (4) Black Andrews ; (5) Kolanka Goa and (6) Jahangir.

(*b*) Bihar :

(1) Langra (Malda) ; (2) Jardalu and (3) Hemsagar.

(*c*) The United Provinces :

(1) Benarsi Langra ; (2) Fazri Zafrani ; (3) Calcutta Amin ; (4) Fazri White ; (5) Naspati and (6) Sali Banda.

(*d*) The Bombay Presidency :

(1) Alphonso ; (2) Raival (country variety) ; (3) Pyree ; (4) Cawasjee Patel ; (5) Shendrya ; (6) Batli ; (7) Borsha ; (8) Fernandez ; (9) Bali ; (10) (11) (12) Kshirsindhu, Khobrya and Manohar from Shivapur.

Selection of fruit for the storage experiments

The procedure followed in preparing fruit for the storage trials was the same with all the varieties under investigation. Only sound fruit, without any injury, blemish or abrasion, was selected. Most of the fruit used for the experiments did not have the stalk-end portion left on it. Further, meticulous care was taken to grade the selected fruit according to the stage of maturity.

Stage of maturity

It is commonly known that a mango fruit can be plucked at several stages of development and, if kept under suitable conditions, the fruit ripens although it may differ in flavour depending upon the stage of maturity at which it was plucked. Many of the choice varieties of mango are not allowed to ripen on the tree, but the fruit is

usually plucked when it is mature according to the requirements of the market. Cheema and Dani [1934] have taken into consideration the factors like the growth of the shoulders, the colour of the fruit and the texture of the flesh. They have defined four stages of maturity as follows :

First or ' A ' stage. The shoulders are in line with the stem-end and the colour of the fruit is oil-green.

Second or ' B ' stage. The shoulders outgrow the stem-end and the colour is oil-green.

Third or 'C' stage. The shoulders outgrow the stem-end and the colour lightens.

Fourth or ' D ' stage. The flesh becomes soft and the blush develops.

Wardlaw and Leonard [1936] have found that similar characteristics are also applicable to the fruits of the Julie variety. The characteristics mentioned above were applicable to most of the varieties investigated but, in a few cases, the stages of maturity had to be fixed individually.

The fruit of ' A ' stage of maturity requires a little longer time to ripen than the fruit of ' B ' and ' C ' stages of maturity. The fruit also keeps for a longer time. But the fruit does not develop proper sweetness and is, therefore, not suitable for the market. The fruit is usually not allowed to remain on the tree to reach ' D ' stage of maturity as the fruit that reaches this stage of maturity on the tree does not possess the proper flavour in many of the varieties and is also quickly perishable.

The fruit of ' B ' and ' C ' stages of maturity was used for the cold storage investigations. ' Ripe ' fruit, originally of ' C ' stage of maturity at the time of picking but ripened at room temperature, was also included in the storage trials. This stage of maturity appears to be similar to the stage described as ' eating maturity ' by Wardlaw and Leonard [1936].

Storage of fruit in the chambers

The fruit was, as a rule, except for the packing and other experiments, kept in open trays in the chambers. The trays were made of deal-wood and were of the size of 24 in.$\times$12 in.$\times$4 in. The trays were made with partly open sides and bottom for good aeration so as to keep the fruit at a uniform temperature. Each tray held about two dozens of fruit of average size. The trays were numbered to facilitate observations in the course of the investigations. At regular intervals, the fruit was examined carefully for visible changes. A few fruits were also cut to see if they were internally sound.

Definition of ' commercial storage life '

A clear explanation of this term is given by McGuire [1931]. In studying the behaviour of a fruit in cold storage, the ' commercial storage life ' has been defined as the length of time the fruit can be stored before the loss due to fungal rots and functional (non-parasitic) diseases amounts to ten per cent.

The fungal diseases were identified by the Plant Pathologist to the Government of Bombay and the chemical work was done in the Chemical Laboratories at the

Agricultural College, Poona. The methods employed for chemical analyses have been described later in this paper.

Variety trials

The results of the storage investigations of the several varieties of mango are described in the following pages :

Varieties from the Madras Presidency

Peter. The Peter is a well known variety in the Madras Presidency and is very common in the Salem District. The Peter is very extensively cultivated on account of its productiveness and early-bearing habit. The fruit of this variety matures early in April and is usually the first to come to the market in the beginning of the mango season. Bombay and Madras are very good markets for this fruit. It cannot be sent to the more distant markets in North India as the fruit spoils on the way.

The fruit for the experiments was obtained from Salem proper and it was in railway transit for about three days. Selected fruit of ' B ', ' C ' and ' ripe ' stages of maturity was kept at 30°, 35°, 40°, 45°, 48°, 52°, 60°, 68°F. and at room temperature (80°F.—96°F.).

The green fruit of ' B ' and ' C ' stages of maturity assumed a boiled-green colour within a week of storage at 30°F. The fruit began to rot immediately after it was transferred to room temperature. The fruit pitted very badly. The juice oozed out from the stem-end. The fruit stored at 35°F. and 40°F. also showed signs of chilling. Pitting and dark brown spotting was commonly noticed. The fruit from these temperatures also started rotting soon after it was transferred to room temperature. The fruit at 45°F. was not affected by pitting but had developed greenish brown specks on the skin. The fruit did not ripen at 45°F. nor did it ripen when it was transferred to room temperature.

The fruit remained in good condition at 48°F. and 52°F. It remained quite green and hard at 48°F. for four weeks and after that period it commenced to turn soft. The fruit after four weeks of storage at 48°F. ripened normally when placed at 68°F. or at room temperature. The fruit at 52°F. ripened well after about four weeks and the colour, taste and flavour were quite satisfactory. The fruit of ' C ' stage of maturity turned brown in portions where the skin was of light green colour.

The yellow colour of ' ripe ' fruit changed to brown at all the temperatures from 30°F. to 52°F. This spoiled only the outward appearance of the fruit. The pulp was not in any way damaged for two or three weeks or even longer at the lower temperatures. The ' ripe ' fruit could be kept in good condition at 60°F. and 68°F. only for a week.

The green fruit ripened satisfactorily at 60°F., 68°F. and room temperature. The temperature of 68°F. was found to develop a good colour on the fruit during ripening. Green fruit kept at this temperature directly or after cold storage at 48°F. or at 52°F. also developed a bright yellow colour which is usually not found on ripe fruit of this variety.

The fruit of 'B' and 'C' stages of maturity did not show much difference in the length of the ripening period at a given temperature. Different temperatures, however, showed their effect on the ripening of fruit (Table I).

TABLE I

Rate of ripening

Temperature of storage	Number of days required for ripening
Room temperature (80°F.—96°F.)	8
68°F.	14
60°F.	18
52°F.	27

With the progress of the storage period some of the fruit commenced to rot usually at a spot near the stem-end. This gradually developed into a deep brown circular area around the stem-end. In addition to this kind of stem-end rot (Plate XV, fig. 1), a few fruits were affected by lateral rot as well. The presence of a species of *Gloeosporium* was found in the rotting portion of the fruit. Practically all the wastage of the fruit was due to the two kinds of rot. The relation of percentage of wastage to the temperature of storage, and the rate of wastage during storage at 52°F. is shown in Tables II and III respectively.

TABLE II

Influence of temperature on the percentage of wastage (after 21 days of storage)

Temperature of storage	Percentage of wastage
Room temperature (80°F.—96°F.)	100
68°F.	78
60°F.	67
52°F.	6

TABLE III

Rate of wastage in storage at 62°F.

Number of days of storage	Percentage of wastage
21	6
27	21
30	35
33	39

It is observed from the above results that 45°F. or the lower temperatures were not favourable for the storage of the Peter fruit as the appearance of the ripe fruit was spoilt by the change to brown colour and as the ripening power of the green fruit was also affected. The fruit could be kept at 48°F. in good condition for four weeks without much wastage and ripened normally at 68°F. when the fruit developed good colour. The fruit could be kept at 52°F. for three weeks but at higher temperatures the wastage was very rapid.

Suwarnarekha. This variety is locally well known to possess a good colour, flavour and keeping quality. The variety probably receives its name from the golden colour of the fruit. The fruit was obtained from Bobbili in the Madras Presidency and was in railway transit for three days. The selected fruit of 'B', 'C' and 'ripe' stages of maturity was kept at 30°, 35°, 40°, 45°, 48°, 52°, 60°, 68°F. and at room temperature (80°F.—96°F.).

The green fruit kept at temperatures from 30°F. to 45°F. did not ripen in the chambers nor did it ripen when exposed to room temperature. There was an appreciable oozing of juice from the stem-end of the fruit at 30°F., 35°F. and 40°F. The colour of the fruit changed to boiled-green and the fruit started decaying soon after 52°F. it was removed from the chambers to room temperature. The green fruit kept at 52°F. remained green and hard for two weeks and then it began to ripen. The green fruit stored at 60°F., 68°F. and room temperature ripened normally and developed a good yellow colour. The development of colour was specially attractive at 68°F. The period required by the fruit to ripen at different temperatures is given in Table IV.

TABLE IV

Rate of ripening

Temperature of storage	Number of days required for ripening
Room temperature (80°F.—96°F.)	9
68°F.	13
60°F.	17
52°F.	20

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FIG. 1. Stem-end rot of Peter fruit

FIG. 2. Lateral rot of Suwarnarekha fruit

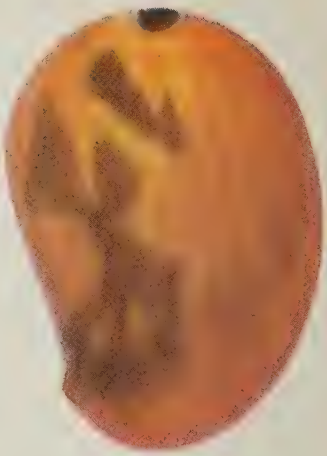


FIG. 3. Brown patches of Suwarnarekha fruit

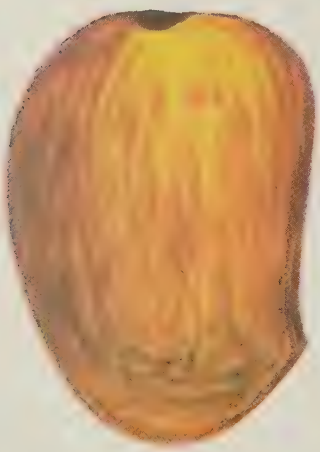


FIG. 4. Browning of Langra fruit

FIG. 5. Browning of the pulp around the stone of Alphonso fruit

The ' ripe ' fruit and some fruit of the ' C ' stage of maturity turned brown at 52°F. and at room temperature. The fruit could be kept in good condition at 60°F. and 68°F. for a week but not for more than three or four days at room temperature. The pulp of the fruit was not spoilt at 52°F. and at lower temperatures although the skin had turned brown. The pulp was edible for a fortnight.

Most of the spoilage of the fruit of Suwarnarekha variety was due to lateral rot (Plate XV, fig. 2). The rotting started as dark brown spots which gradually spread all over the skin, developing into circular patches with soft and brown flesh underneath the decaying portion. About sixty per cent of the total wastage was due to lateral rot only. The other fruit started rotting near the stem-end and the skin was rendered translucent with watery flesh inside. This type of rotting is described as ' watery rot '. The decayed portion usually became too soft to bear any pressure.

The behaviour of the green fruit of Suwarnarekha variety which called for special attention was the disfigurement probably due to the attack of a kind of pathogen on the skin. The fruit at the time of keeping it in the storage chambers was quite clean and free from any blemish on the skin. A few days after storage there appeared faint signs of brown patches on the skin of some of the fruit. It was observed that these patches gradually developed and began to spread all over the skin (Plate XV, fig. 3). In the early stages the growth of ' brown patches ' was limited to the skin only and did not affect the pulp, but later on, these patches formed the centres of lateral or ' watery rot ' along with the dark brown spots on the skin. An examination of the fruit affected by ' lateral rot ', ' brown patches ' and ' watery rot ' showed the presence of a species of *Gloeosporium* in each case.

The extent of the development of ' brown patches ' on the fruit in cold storage is shown in Table V.

TABLE V

Percentage of fruit affected by ' brown patches '

Temperature of storage	Number of days of storage	Percentage of ' brown patches '
45°F.	14	54
48°F.	14	69
52°F.	14	69

The development of ' brown patches ' appeared to be a characteristic of this variety. A careful examination showed the presence of such brown patches on some of the fruit received for the experiment just after unpacking. The development was, therefore, not limited to fruit in cold storage only. The marks were, however, masked by the bright colour of the ripe fruit as the development was only slight.

Further, the fruit used in the 1934 season was obtained from Bobbili. In 1935, the fruit was obtained from Alamanda. The behaviour of the fruit from the two localities was practically the same. Experiments on washing the fruit with copper sulphate solution or smearing with zinc oxide powder before putting it into the cold chambers showed that neither of the treatments was of any advantage in preventing the development of ' brown patches '.

The rate of wastage was comparatively slow at 45°F. and 48°F., but the ' brown patches ' spoiled the appearance of the green fruit in cold storage and the fruit rotted quickly when it was placed at 68°F. for ripening. Temperatures of 52°F. and lower were, therefore, not suitable for storage of green or ripe fruit of this variety. The temperatures, 60°F. and 68°F., were found to check the process of decay to some extent both in the green and in the ripe fruit and thus extend the ' storage life ' by a few days only without impairing the quality of the fruit.

Banganpalli. Banganpalli is a well-known table variety. The fruit is broad and flat and assumes bright yellow colour on ripening. The pulp is firm and of an excellent taste and flavour. This is an important commercial variety in the Godavari District. The fruit for the cold storage trials was obtained from Alamanda.

Fruit of ' B ' and ' C ' stages of maturity was received from Alamanda. The fruit was in transit for about three days and during this period some of the fruit had started to turn yellow. The fruit was, therefore, sorted into three lots, (i) green and hard ; (ii) ' turning ' and (iii) yellow and ripe. It was difficult to divide the green fruit into ' B ' and ' C ' stages of maturity. The graded fruit was kept at 43°, 45°, 48° and 52°F. only.

The yellow and ripe fruit turned brown within a fortnight of storage at the different temperatures. Only the skin of the fruit was affected. The pulp of the fruit was in good condition for a month at 43°F. and 45°F. The behaviour of green and of some of the ' turning ' fruit at the different temperatures resembled that of the Suwarnarekha fruit as regards the development of ' brown patches ' on the skin. The extent of this development could be seen from the percentage of fruit affected by it. The nature of the development was similar to that on the Suwarnarekha fruit.

TABLE VI

Percentage of fruit affected by ' brown patches'

Temperature of storage	Number of days of storage	Percentage of ' brown patches '
43°F.	17	100
45°F.	26	75
48°F.	14	35
52°F.	12	37

Most of the decay of the fruit was due to ' watery rot ' which has been described in the case of the fruit of Suwarnarekha variety. The wastage was within ten per cent after a month of storage at 43°F. and 45°F. only, but otherwise the rotting was rapid (Table VII).

TABLE VII

Percentage of wastage in storage

Temperature of storage	Number of days of storage	Percentage of wastage*
43°F.	33	9
43°F.	42	29
43°F.	61	81
43°F.	67	100
45°F.	33	7
45°F.	40	21
45°F.	46	68
45°F.	63	94
48°F.	25	12
48°F.	32	43
48°F.	38	82
48°F.	43	91
52°F.	12	2
52°F.	25	60
52°F.	32	85
52°F.	37	91
52°F.	43	94

* The number of fruits affected by ' brown patches ' are not included under wastage by rotting.

An examination of the fruit affected by ' watery rot ' and ' brown patches , showed the presence of *Gloeosporium* sp. Though the wastage was within 10 per cent at 45°F. after thirty-three days of storage, the percentage of fruit affected by ' brown patches ' was 75 after twenty-six days of storage. The growth of ' brown patches ', therefore, rendered the fruit unsuitable for commercial cold storage.

Black Andrews. The unripe fruit of this variety is dark green in colour and big and roundish in appearance. The fruit of 'B' and 'C' stages of maturity was obtained from Alamanda. Some of the fruit was allowed to ripen at room temperature and then exposed to temperatures from 43°F. to 52°F. The yellow colour of the fruit soon turned brown.

The dark green fruit of 'B' and 'C' stages of maturity retained the original colour until it showed signs of decay by the development of dark brown spots on the skin. The rate of wastage at the different temperatures of storage is given in Table VIII.

TABLE VIII

Percentage of wastage in storage

Temperature of storage	Number of days of storage	Percentage of wastage
43°F.	33	0
43°F.	40	18
43°F.	59	62
43°F.	65	71
45°F.	31	1
45°F.	38	16
45°F.	44	26
45°F.	59	71
45°F.	64	86
48°F.	29	6
48°F.	35	16
48°F.	40	55
48°F.	56	92
52°F.	23	7
52°F.	30	50
52°F.	35	67
52°F.	41	86
52°F.	45	100

The above values for the percentage of wastage were plotted against the number of days of storage from which it was deduced that the ten per cent wastage was noticed at 43°, 45°, 48° and 52°F. after thirty-seven, thirty-five, thirty-one and twenty-four days respectively. The green fruit stored at the above temperatures even for a fortnight did not ripen properly when removed to 68°F. or to room temperature, but started rotting. The fruit was, therefore, found unsuitable for cold storage.

Kolanka Goa. This is a late table variety and its fruit is of medium size. The fruit possesses poor flavour but keeps well and stands transport. The fruit was obtained from Alamanda. In the railway transit some of the fruit of ' B ' and ' C ' stages of maturity ripened and turned yellow while most of the remaining fruit became soft, but the green colour was not changed.

Unlike the fruit of the other varieties described so far the ripe fruit of this variety did not turn brown but remained in good condition for three weeks at the temperatures of 35°F. to 43°F. The green fruit stored at the temperatures of 43°F. to 52°F. did not ripen when removed to room temperature, though the percentage of wastage was not appreciable for the first four weeks of storage at 43°F. and 45°F. The nature of rotting of the fruit of this variety differed from that of the fruit of the other varieties in that the rotting usually started from the tip-end where dark colouration gradually developed. The green fruit was, therefore, found unsuitable for cold storage.

Jahangir. Jahangir is a good table variety and is famous in some parts of the Madras Presidency, particularly, in the East Godavari District. The fruit is famous for its flavour and colour of the pulp.

The fruit for experiment was obtained from Rajahmundry. All the fruit was received here in a more or less ripe yellow condition. The fruit stored at 43°F. and the lower temperatures turned brown soon after being kept. At 45°F. the fruit shrivelled and there was a development of brown specks after four weeks of storage. Although the outward appearance was thus affected the pulp of the fruit was in good condition for six weeks at 45°F. The fruit became highly shrivelled at 48°F. and 52°F. within two weeks.

From the results of the cold storage trials of the six varieties of mango from the Madras Presidency, it appears that Peter is the only variety which shows a satisfactory keeping quality in cold storage. The fruit of ' B ' stage of maturity could be kept in good condition for four weeks at 48°F. The appearance of the fruit of Suwarnarekha and Banganpalli varieties was spoiled due to the growth of ' brown patches ' and so the varieties were found unsuitable for cold storage. Even pre-storage treatments such as washing with copper sulphate or smearing with zinc oxide powder failed to check the growth of ' brown patches '. The green fruit of Black Andrews and Kolanka Goa varieties could be kept in good condition without much wastage at 43°F. and 45°F. for about a month but the fruit did not ripen when placed at room temperature. The ripe fruit of Kolanka Goa variety could be stored in good condition at the low temperatures of 35°F. to 43°F. as it did not turn brown like the ripe fruit of the other varieties. The yellow fruit of Jahangir variety turned brown at 45°F.

and the lower temperatures, and became shrivelled and developed brown spots at 48°F. and 52°F.

Varieties from Bihar

Langra. The fruit of this variety, which is also known locally as Malda, was obtained from Sabour. The green fruit of this variety appears slightly dark in colour. The fruit with its thin skin and sweet juicy pulp is famous in Bihar and the United Provinces.

The green mature fruit started ripening and turned yellow in railway transit of about three days. The fruit was, therefore, divided into three lots, (i) green and hard; (ii) ' turning ' and (iii) yellow. The fruit of all the three lots turned brown (Plate XV, fig. 4) at temperatures of 35°F. to 52°F. At 60°F. and 68°F. the yellow and ' turning ' fruit suffered from both the stem-end and lateral rots. The green fruit was affected in the same manner before it had a chance to ripen. The brown colour spoiled the appearance of the ripe fruit but the pulp remained entirely unaffected. The pulp was found to be sweet and juicy after six weeks of storage at 45°F. The brown skin could be easily peeled off.

Jardalu. The green fruit despatched from Sabour was received here in ripe and yellow condition. The yellow fruit turned brown at different temperatures from 35°F. to 52°F. As in the case of the fruit of Langra variety, the change in colour reduced the commercial value of the fruit. The pulp remained in good condition for six weeks at 43°F. and 45°F.

Hemsagar. The green fruit despatched from Sabour showed, on arrival, dark spots near the stem-end. The fruit could not be kept for any appreciable time in the cold chambers as it began to rot very rapidly.

From the results of the trials of the above three varieties it can be seen that the pulp of ripe fruit of Langra and Jardalu varieties could be preserved at 45°F. for six weeks although the market value of the fruit was lost as the colour of the skin turned brown in cold storage.

Varieties from the United Provinces

Benarasi Langra. The fruit of ' B ' and ' C ' stages of maturity was obtained from Saharanpur. But it became soft after the three days of railway transit—the green colour being unaffected. The fruit was kept at 43°, 45°, 48° and 52°F. The fruit commenced rotting after thirty-one days of storage at 45°F. The green fruit was in sound condition at 45°F. but did not ripen when transferred to 68°F. It started rotting.

Fazri Zafrani. The fruit of ' B ' and ' C ' stages of maturity was received from Saharanpur. Some of the fruit turned yellow during transit and some was just turning yellow. The fruit was, therefore, graded into three lots, (i) green, (ii) ' turning ' and (iii) yellow.

The ripe yellow fruit of this variety did not turn brown in cold storage but remained in a very good condition for about five weeks at 43°F. and 45°F. The

' turning ' and green fruit remained in good condition in the cold chambers at 43°F. and 45°F. for over a month, but it did not ripen satisfactorily when transferred to 68°F. nor did it ripen at room temperature. By the time the fruit turned yellow it started rotting.

It was noted that the rate of wastage due to rotting in storage depended on the grade of the fruit. The percentage of wastage of the three lots of fruit at the different temperatures is given in Table IX.

TABLE IX

Percentage of wastage in storage

Temperature of storage (°F.)	number of days of storage	Percentage of wastage		
		Green	Turning	Yellow
43	26	0	0	0
43	36	0	2	28
43	45	13	24	72
43	54	67	100	100
43	66	85	..	..
45	25	0	2	0
45	33	1	13	4
45	38	3	26	12
45	45	16	53	64
45	54	52	80	100
45	61	83	100	..
48	18	0	0	4
48	23	0	0	76
48	32	27	66	80
48	38	48	89	100
48	50	77	98	..
52	17	0	60	50
52	23	21	94	100
52	30	70	100	..

It is observed that in the case of yellow fruit stored at 43°F. and 45°F. the ten per cent wastage was noticed between four and five weeks of storage. The rate of wastage of ' turning ' fruit was lower than that of yellow fruit, except at 45°F. where the rate was higher for the first six weeks of storage. The rate of wastage of green fruit was comparatively low. The values of the percentage of wastage in green fruit have been plotted in Fig. 1 from which it can be seen that ten per cent wastage was noticed after forty-two days of storage at 45°F. But the green fruit did not ripen satisfactorily when transferred to 68°F. or to room temperature. Only the ripe fruit could be kept in good condition for about five weeks at 43°F. and 45°F.

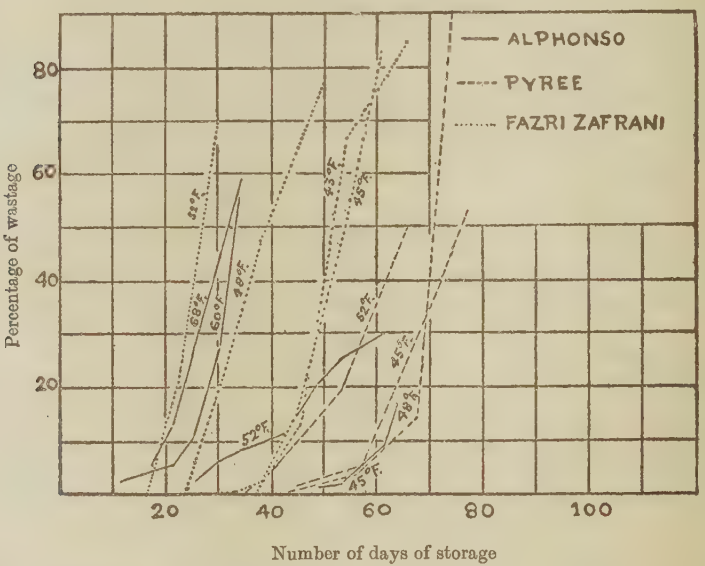


Fig. 1. Percentage of wastage in storage of Alphonso, Pyree and Fazri Zafrani fruit

Calcutta Amin. The fruit of ' B ' and ' C ' stages of maturity was received here from Saharanpur in a firm and green condition. The skin of the fruit showed dark brown spots which was reported to be one of the characteristics of this variety.

The fruit remained without any wastage for five weeks at 43°F. and 45°F., but this fruit did not ripen when transferred to 68°F. Rotting of fruit commenced with the further development of the dark brown spots. The fruit then rotted quickly and within a week about fifty per cent of the fruit was lost. The values of the percentage of wastage at the different temperatures are given in Table X.

TABLE X

Percentage of wastage in storage

Temperature of storage (°F.)	Number of days of storage	Percentage of wastage
43	37	0
43	46	45
43	58	80
45	37	3
45	46	54
45	53	100
48	25	6
48	31	55
48	37	80
48	43	95
52	15	7
52	22	66
52	30	96

Fazri White. The fruit of 'B' and 'C' stages of maturity was obtained from Saharanpur. It was received here in a firm and green condition without any wastage in transit and kept in good condition without any loss for four weeks at 43°F. and 45°F. The fruit, however, did not ripen when transferred to 68°F., but it rotted. The fruit, when it commenced to decay, rotted quickly (Table XI).

TABLE XI

Percentage of wastage in storage

Temperature of storage (°F.)	Number of days of storage	Percentage of wastage
43	29	0
43	38	80
43	50	100
45	29	0
45	38	61
45	45	100
48	16	1
48	22	15
48	28	43
48	34	90
48	41	100
52	14	9
52	22	61
52	28	89
52	34	100

Naspati. The fruit was received here in a soft condition and, on being kept in the cold chambers, it rotted within a fortnight at all temperatures from 43°F. to 52°F.

Sali Banda. The fruit of this variety had turned brown when it was received from Saharanpur. The browning developed further in the storage chambers. The fruit completely rotted within a fortnight.

Gopal Bhog. The fruit reached here in a green and firm condition. It remained green and hard without any wastage for four weeks at 45°F. but this fruit failed to ripen properly when transferred to 68°F. After four weeks of storage of 45°F. the fruit developed dark brown spots and began to rot. Seventy-five per cent of the fruit rotted within a week, i.e., after five weeks of storage.

From the results of the trials of the seven varieties from the United Provinces it will be observed that the fruit of none of the varieties tested, except Fazri Zafrani, was suitable for cold storage. The storage behaviour of green Fazri Zafrani fruit was not very satisfactory, but ripe yellow fruit of this variety could be kept in a good condition for about five weeks at 43°F. and 45°F.

There are some other good varieties, like Dasehri and Sufeda grown in the United Provinces which have not yet been tested. The cold storage trials of these varieties have now been undertaken and it is possible that they might be found quite suitable.

Varieties from the Bombay Presidency.

Alphonso. The Alphonso variety is very well known for its quality all over India. It is chiefly grown in the Konkan. The fruit of this variety has normally a good keeping quality. The first experimental export shipments by Cheema and Dani [1934] consisted, for a major part, of fruit of this variety. The fruit reached London in fairly good condition even when stowed on deck of the P. and O. mail steamers.

The green fruit of ' B ' and ' C ' stages of maturity and ' ripe ' fruit was kept at the temperatures from 30°F. to 68°F. and at room temperatures. The fruit for these experiments was obtained from Achhar near Karabele in the Thana District.

Ripe yellow fruit turned brown immediately at 52°F. and the lower temperatures. The browning of the skin affected only the appearance of the fruit, at least for the first few weeks, as otherwise the pulp tasted well. The over-ripe fruit did not turn brown at the above temperatures. The ripe fruit could be kept in good condition for about two weeks at 60°F., for ten days at 68°F. and for a week at room temperature.

The green fruit of both the ' B ' and ' C ' stages of maturity at the temperatures of 30°, 35° and 40°F. was spoiled pretty quickly. The symptoms were the same as those observed in the case of the fruit of Peter and Suwarnarekha varieties. The juice oozed from the stem-end. The skin assumed boiled green colour and showed pitting. Of course, the intensity of damage in each case varied according to the temperatures of storage. The fruit from 30°F. and 35°F., after storage for a week, did not ripen, but started rotting immediately when kept at 68°F. The fruit after storage for three to four weeks at 40°F. developed a yellow colour in patches when exposed to 68°F. The flesh assumed a rubbery texture and there was a browning of the pulp around the stone (Plate XV, fig. 5).

The fruit of both the ' B ' and ' C ' stages of maturity remained in a firm and green condition for about nine weeks at 45°F., but some of the fruit of ' C ' stage of

maturity turned brown in parts where the skin showed a slight yellowish colour. The fruit showed faint signs of the development of a pale yellow colour after nine weeks. The fruit stored for nine weeks ripened well when transferred to 68°F. The pulp of the fruit stored at 45°F. for seven to nine weeks, and then ripened at 68°F. developed a rubbery texture and was found less sweet. After nine weeks of storage the pulp around the stone commenced to assume a brown colour.

The fruit of both the stages of maturity began to turn yellowish after four weeks of storage at 52°F. The fruit turned yellow and became ripe after seven weeks. A few dark green specks were visible on the skin. The fruit had a fresh orange pulp but the texture appeared somewhat coarse. The fruit, stored for four to five weeks in good condition at this temperature, ripened well when kept at 68°F. and compared favourably with that ripened under normal conditions.

The fruit stored at 68°F. ripened normally to a good colour. The fruit stored at 60°F., however, showed some green spots. The characteristic pleasant flavour of the Alphonso fruit was lost at these temperatures, but it developed again when the fruit was transferred to room temperature. The fruit began to get over-ripe after three weeks at 68°F. and after about four weeks at 60°F. The over-ripe fruit tasted flat. Later on, it showed browning around the stone.

The fruit of ' C ' stage of maturity ripened a little earlier than the fruit of ' B ' stage of maturity. The rate of wastage in fruit of ' C ' stage was, however, slightly higher than that in fruit of ' B ' stage. The rates of ripening of fruit of ' B ' stage of maturity at different temperatures are given in Table XII.

TABLE XII

Rate of ripening

Temperature of storage	Number of days required for ripening
Room temperature—	
(80°—96°F.)	8
68°F.	12
60°F.	18
52°F.	48
45°F.	66 (just yellowish)

The Alphonso variety exhibited itself as the most promising variety from the very start. There was no appreciable loss due to wastage even at room temperature

for two weeks in the beginning, a period when all other varieties showed a high percentage of wastage. The values of the percentage of wastage of fruit of 'B' stage of maturity are given in Table XIII.

TABLE XIII

Percentage of wastage in storage

Temperature of storage (°F.)	Number of days of storage	Percentage of wastage
68	17	5
68	21	12
68	25	26
68	30	45
68	34	59
60	11	2
60	17	4
60	21	5
60	25	10
60	30	27
60	34	56
52	25	2
52	30	6
52	34	8
52	42	11
52	48	20
52	53	25
52	61	30
45	48	1
45	53	2
45	61	9
45	63	17

These figures have been shown graphically in Fig. 1. It is seen that it was only after forty-two days of storage at 52°F. that the loss reached ten per cent. At 45°F. there was no appreciable loss for fifty-three days, the ten per cent wastage being reached only after sixty-one days of storage.

At 68°, 60° and 52°F. most of the wastage was due to stem-end rot. At 45°F., however, the wastage was due to the development of dark brown circular areas on the hard green fruit. The cause of both the kinds of decay was found to be a species of *Gloeosporium*.

From the above results described in detail, it is observed that ' B ' stage of maturity was more suitable for cold storage as the fruit of ' C ' stage turned brown and developed brown colour around the stone rapidly. The fruit of ' B ' stage of maturity could be stored in green condition for four weeks at 52°F. and for seven weeks at 45°F. This fruit ripened satisfactorily when transferred to 68°F. where it could be kept for a further period of ten days. The difference between the two temperatures of 45°F. and 52°F. was wide. An intermediate temperature of 48°F. was therefore, arranged for the locality trials of Alphonso variety described later.

Raival (*country variety*). A big trade exists in Bombay in tender fruit used for pickling purposes in the beginning of the season. The observations on tender mangoes obtained from Ratnagiri showed that the fruit could be kept at 45°F., in a fresh condition, for about three weeks.

The Raival fruit of ' B ' stage of maturity despatched from Ratnagiri was received here in ripe yellow condition. The ripe fruit turned brown in the cold chambers within a week of storage.

Pyree. The fruit of this variety was obtained from a garden near Poona, The fruit of ' B ' stage of maturity which was green and firm was selected for the experiments. The fruit was stored at 45°, 48°, 52° and 68°F. It was found in a preliminary trial that fruit which was of an advanced stage of maturity (' C ' stage) turned soft in cold chambers and that at temperatures lower than 45°F., chilling was observed.

The fruit at 45°F. remained in a hard and green condition for about eight weeks. Then some of the fruit began to get soft and appeared slightly shrivelled. There was also an oozing of a sticky juice from the stem-end portion of the fruit. There appeared, later on, a fungal growth at the tips where the juice oozed out.

The fruit at 48°F. remained in a hard and green condition for five weeks. After this period it began to turn soft and appeared slightly shrivelled. The sticky juice oozed out and fungal growth appeared on the tips of the stem-end.

At intervals during the storage period a few fruits were removed from 45°F. and 48°F. and kept at 68°F. for ripening. The ripe fruit of this variety is generally only yellowish green but not completely yellow. The ripening at 68°F., however developed a good yellow colour. The taste and condition of the fruit so ripened are given in Table XIV.

TABLE XIV

Taste and condition of fruit ripened at 58°F. after cold storage

Number of days of storage	Taste and condition of fruit	
	45°F.	48°F.
29	Yellow flesh, good taste, little sour .	Yellow flesh, good taste, little sour
49	Yellow flesh, good taste, little sour .	Pale yellow and soft flesh, sour
60	Development of brown pulp around the stone	Development of brown pulp around the stone

The fruit at 52°F. turned soft after three weeks of storage. The green colour did not change in the beginning but turned yellowish after five weeks. The soft fruit, when cut, showed a pale yellowish pulp and tasted very sour. The browning of the pulp around the stone was noticed after eight weeks of storage.

There was no wastage for the first six weeks at 45°F. and 48°F. and for five weeks at 52°F. The percentage of wastage at 45°, 48° and 52°F. at different periods of storage is given in Table XV.

TABLE XV

Percentage of wastage in storage

45°F.		48°F.		52°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
44	1	43	0	35	0
57	5	56	3	41	5
72	40	67	14	53	19
77	53	74	100	66	50

The above values have been represented graphically in Fig. 1 from which it will be seen that ten per cent wastage was noticed after fifty-nine days at 45°F. and after sixty-three days at 48°F. The fruit, however, could be kept in good condition at 45°F. and 48°F. for seven weeks only as storage for a longer period developed a brown pulp around the stone on ripening.

Cawasjee Patel. The fruit of this variety was obtained locally. Green fruit of 'B' stage of maturity was selected. The fruit remained in good condition without any loss for nine weeks at 48°F. and 52°F. The fruit ripened properly and developed a good colour when kept at 68°F. After storage for more than nine weeks at 48°F. and 52°F., the fruit began to change its colour, but the pulp around the stone turned black.

There was no loss at 43°F. and 45°F. for ten weeks, the fruit remaining hard and green. The fruit kept at 43°F. did not ripen properly when removed to 68°F. The fruit from 45°F. ripened satisfactorily. The pulp of the fruit ripened after nine weeks of storage was black around the stone.

The fruit of this variety showed a good keeping quality in cold storage. The fruit, however, is of an inferior quality for table use and is mainly used for pickles.

Shendrya. The green and hard fruit of this variety was obtained locally for the experiment. The fruit retained a good outward appearance for eight weeks at 48°F. and 52°F., and for more than ten weeks at 43°F. and 45°F. But the fruit did not ripen properly when transferred to 68°F. after different periods of storage at all the above temperatures. They became soft, developed dark brown spots on the skin and the whole pulp turned brown. The green fruit, after about seven weeks of storage in the cold chambers, also showed brown pulp when cut. As the green fruit remained in good condition for six weeks in cold storage, it appears that the fruit could be stored for pickling purposes.

Batli. The fruit of this variety is reported to possess some of the qualities of the Alphonso variety. Hence, the variety is known as 'Batli' (bottle-shaped) Alphonso. The fruit was obtained from Bulsar in the District of Surat. Ripe yellow fruit turned brown in the cold chambers. The green and hard fruit remained in good condition for nine weeks at 45°F. without any loss. But the ripening of the fruit when transferred to 68°F. was not as satisfactory as that of the Alphonso fruit under similar conditions.

Borsha. This is a well-known variety in the East Khandesh District. The fruit was obtained from the mother tree of this variety. The green and hard fruit turned soft in the cold chambers and decayed rapidly when transferred to 68°F.

Fernandez. This variety is grown mainly in the Goa Territory and the fruit is sent to the Belgaum market where it is sold under the name of 'Goa Alphonso'. The fruit for the storage experiment was obtained from Belgaum. The observations in the 1935 season showed that both the green and ripe fruit of this variety could be kept in good condition for eight weeks at 45°F. and 48°F. The green fruit ripened satisfactorily when removed to 68°F. The fruit in the 1936 season, ho ever, did not keep so well, but rotted rapidly.

Bali. This variety is grown in the Dharwar District. The fruit was yellow when it was received from Dharwar. It turned brown within a week of storage in the cold chambers.

Kshirsindhu, Khobrya and Manohar. The green and firm fruit of the above three varieties grown at Shivapur, a place famous for the cultivation of country

varieties of mango, was kept at 48°F. The fruit remained in good condition for six weeks without any loss. The pulp was unaffected for this period of storage. The fruit did not ripen when transferred to 68°F., but began to rot. The fruit of these varieties is generally used for pickles and preserves. It is possible to store the fruit, for this purpose, at 48°F. for six weeks.

The results of the storage trials of the twelve varieties of Bombay mango showed that the green fruit of ' B ' stage of maturity of Alphonso and Pyree varieties could be kept in good condition for nine and seven weeks respectively at 45°F. The suitable range of temperatures for storing the fruit of the two varieties appeared to be between 45°F. and 48°F. The fruit of Cawasjee Patel, Shendrya and the three Shivapur varieties could be stored at 48°F. in green condition for a period of six weeks for use in pickles and other preserves. The Cawasjee Patel variety was found to be a good keeper in cold storage, but the fruit is of an inferior quality and is not much used for table purposes.

Locality trials

The mango appears to grow well in a wide range of soils and in a variety of climatic conditions. But the same variety grown under the climatic conditions of different localities is reported to vary in character [Cheema and Dani, 1934]. For instance, the Alphonso mango grown at Ratnagiri develops a far better hue than that grown at Thana or at Surat, but the size of the Alphonso fruit grown in the Surat District is generally bigger than that grown either in Ratnagiri or in Poona. The Alphonso mango grown in Dharwar is good in taste but lacks in the keeping quality usually found in the case of the fruit of this variety from the other localities.

Preliminary experiments to determine the effect of the locality of production on the storage behaviour of the fruit of Pyree and Batli varieties were carried out. The fruit of Pyree variety was obtained from Poona and Ratnagiri and that of Batli variety from Poona and Bulsar in the Surat District. No marked difference was found in the storage behaviour.

A detailed investigation into the effect of the locality of production on the cold storage behaviour of mango was carried out in the case of the Alphonso variety as this variety was found to keep well in cold storage and the results obtained were found to be of commercial importance. It was for the same reason that further experiments on the use of different packing materials, the effect of wrapping fruit in papers, etc., were carried out on the fruit of this variety.

The Alphonso mango-growing tracts in the Bombay State are divided into five groups by Cheema and Dani [1934] who have also noted that the fruit from these five groups varies in character to some extent. The chief difficulty in conducting experiments on the fruit from all the five groups at one and the same time was due to the fact that the fruit does not mature at the same time in all these tracts. Ratnagiri fruit matures earlier than the Bombay fruit. By the time the Bombay season advances, Surat and Dharwar fruit is ready. The fruit grown in Poona matures very late.

The climatic and soil conditions, as described by Sahasrabuddhe [1929], of the different localities from which the Alphonso fruit was obtained are given in Table XVI.

TABLE XVI

Climatic and soil conditions of the different localities

Locality	Nature of country	Nature of soil	Climatic conditions
1. Ratnagiri	Hilly and on the coast	Red laterite (Varkas)	Moist, 80-105 inches of rain
2. Poona	Deccan Plateau	Alluvial loamy	Dry, 20-30 inches of rain, hot summer
3. Thana	Low land intersected by hilly tracts on the coast	Varkas with light colour	Moist, 66-100 inches of rain
4. Surat	Plains near the coast	Alluvial light gorat (rich soils).	40-53 inches of rain, hot summer
5. Dharwar	Plains, inland, on the borderland of hilly tracts	Red soils	Medium rains, mild summer

The fruit of ' B ' stage of maturity was used in the experiments. The fruit was kept at 43°, 45°, 48° and 52°F. The condition of the fruit was examined at intervals.

Ratnagiri

The fruit used in the experiments was obtained from the Ratnagiri Agricultural Farm, Shirgaon. The fruit was despatched from Ratnagiri in a motor bus and was in transit for two days. The influence of the temperature of storage on the ripening of the fruit is given in Table XVII.

TABLE XVII

Relation of temperature to ripening

Temperature of storage (°F.)	Number of days of storage	Appearance of the fruit
43	75	Green
45	75	Just turning
48	75	Yellowish green
52	75	Pale yellow

Fruit stored at 43°F. The fruit remained in a hard and green condition for eleven weeks without any loss. After nine weeks of storage the fruit showed faint signs of the development of brown pulp around the stone. The brown colour deepened when the fruit was removed to room temperature. The storage for more than two weeks at 43°F. affected the ripening power of the fruit though the fruit appeared to keep very well for nine weeks as there were no visible signs of any damage. The green colour of the fruit did not change completely to yellow when it was transferred to 68°F. or to room temperature and the pulp was not sweet and juicy.

Fruit stored at 46°F. The fruit remained in a green and firm condition for more than ten weeks. Some of the fruit after eight weeks of storage began to show dark brown spots on the skin and started rotting. The 10 per cent wastage was observed after 60 days of storage.

Fruit stored at 48°F. The fruit remained in a hard and green condition for six weeks. It started changing colour gradually and was yellowish green and slightly soft after ten weeks of storage. There was no rotting for the first six weeks but started after this period and the 10 per cent loss was noticed after 55 days.

Fruit stored at 62°F. The fruit began to change colour after four weeks of storage turned yellowish green after seve weeks and was pale yellow and only slightly soft after ten weeks. The 10 per cent wastage was recorded after 48 days. The yellowish green and pale yellow fruit did not keep well even for a week when removed to 68°F. or to room temperature.

At intervals during the storage period, some fruit was removed from 45°, 48° and 52°F. and kept at 68°F. for ripening. The taste and condition of this fruit are given in Table XVIII.

TABLE XVIII

Taste and condition of fruit ripened at 58°F. after cold storage

Temperature of storage (°F)	Number of days of storage	Taste and condition of fruit
45	37	Good yellow colour, good flavour, juicy and sweet pulp
45	50	Good yellow colour, juicy and sweet pulp
45	62	Good yellow colour, slightly tough pulp
45	75	Good yellow colour, tough pulp, development of dark colour of pulp around the stone
48	37	Good yellow colour, good flavour, juicy and sweet pulp
48	50	Good yellow colour, juicy and sweet pulp
	62	Good yellow colour, fibrous pulp

TABLE XVIII—contd.

Taste and condition of fruit ripened at 59°F. after cold storage—contd.

Temperature of storage (°F.)	Number of days of storage	Taste and condition of fruit
48	75 (Turned yellowish green in the chamber)	Good yellow colour, fibrous pulp, development of dark colour of pulp around the stone.
52	37	Good yellow colour, good flavour, juicy and sweet pulp
52	50 (Turned yellowish green in the chamber)	Good yellow colour, fibrous pulp
52	62	Good yellow colour, coarse pulp
52	75	Dark colour of pulp around the stone

It can be seen that the storage at 45°F. and 48°F. for seven weeks did not appreciably affect the quality of the fruit. After nine weeks the pulp of the fruit from 45°F. became slightly tough, whereas the pulp of the fruit from 48°F. was slightly fibrous. After ten weeks the pulp around the stone was dark in both the cases.

The percentage of wastage of fruit stored at 45°F. and 48°F. at different periods of storage is given in Table XIX.

TABLE XIX

Percentage of wastage in storage

45°F.		48°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
55	2	51	6
62	13	62	18
72	19	72	38
79	40	82	66

From the above results it will be seen that the ' storage life ' of the fruit was sixty days at 45°F., fifty-five days at 48°F. and forty-eight days at 52°F. The

green and hard fruit kept at 43°F. for more than two weeks failed to ripen properly when removed to 68°F. The green and hard fruit from 45°F. and 48°F. ripened in a week at 68°F. and could be kept in the ripe condition for a week more. The fruit from 52°F. did not keep so long at 68°F. when transferred after five weeks of storage. The range of temperature, 45°F. to 48°F., appeared to be suitable for cold storage of the fruit as it could be stored in good condition for seven weeks.

Poona

The fruit required for these trials was obtained from trees at the Ganeshkhind Fruit Experiment Station, Kirkee, where the Cold Storage Research Scheme is housed. The fruit was kept in the cold chambers directly after picking. The influence of temperature on the ripening of the fruit is given in Table XX.

TABLE XX

Relation of tempearture to ripening

Temperature of storage (°F.)	Number of days of storage	Appearance of the fruit
43	84	Green
45	72	Just turning
48	55	Yellow and ripe
52	42	Yellow and ripe

Fruit stored at 43°F. The fruit remained in a hard and green condition for twelve weeks. After two or three weeks of storage the green fruit did not ripen properly when removed to 68°F. or to room temperature although the skin showed a good yellow colour. There was no wastage for eight weeks. There was eight per cent wastage after sixty-seven days of storage and 17 per cent after seventy-three days.

Fruit stored at 46°F. The fruit remained in a hard and green condition for ten weeks. After this period it began to change colour. There was no rotting for the first eight weeks but then the fruit showed the development of dark brown spots. The 10 per cent wastage was noticed after seventy-four days of storage.

Fruit stored at 48°F. The fruit remained in a hard and green condition for the first four weeks. It started changing colour and turned yellow after eight weeks. The fruit so ripened could be kept in good condition for a week more. The fruit which ripened in the chamber did not keep well at room temperature for more than two days, the pulp around the stone becoming dark brown after this period. The hard and green fruit for the first four weeks of storage and also the fruit just changing colour up to six weeks ripened well at 68°F. or at room temperature and could be kept in good condition for a week. There was no rotting until the seventh week

and the loss was only three per cent on the forty-eighth day of storage. The ten per cent wastage was noticed on the fifty-fifth day.

Fruit stored at 62°F. The fruit remained green for three weeks only and then it commenced to show a change of colour. The fruit was fully ripe and yellow after six weeks of storage and was in good condition for a week more. The ripe fruit did not keep for a long time when it was taken out of the chamber. It was fit for use for a short period only. In the beginning there was no wastage for the first six weeks but the ten per cent wastage was observed on the forty-ninth day of storage.

At intervals during the storage period a few fruits were removed to 68°F. for ripening. The taste and condition of the fruit so ripened are given in Table XXI. It can be seen that although the ten per cent loss was observed after seventy-four days of storage at 45°F. the fruit could not be kept longer than nine weeks without being affected, as after this period the pulp of the fruit ripened after removal to 68°F. was tough and after ten weeks of storage the tissues around the stone turned dark brown.

TABLE XXI

Taste and condition of fruit ripened at 58°F. after cold storage

Temperature of storage (°F.)	Number of days of storage	Taste and condition of fruit
45	40	Good yellow colour, good flavour, juicy and sweet pulp
45	52	Good yellow colour, juicy and sweet pulp
45	64	Good yellow colour, slightly tough pulp
45	75	Good yellow colour, tough pulp, dark colour of pulp around the stone
48	40	Good yellow colour, good flavour, juicy and sweet pulp
48	52 (Ripe in the storage chamber)	Yellowish green colour; yellow, fibrous and slightly acid pulp
48	64 (Ripe in the storage chamber)	Yellow colour; yellow, fibrous, juicy and sweet pulp
48	75 (Ripe in the storage chamber)	Yellow colour; soft and fibrous pulp; over-ripe and flat taste
52	40 (Ripe in the storage chamber)	Yellow colour; yellow, fibrous juicy and sweet pulp
52	52 (Ripe in the storage chamber)	Yellow colour; yellow, soft, fibrous, juicy and sweet pulp
52	64 (Ripe in the storage chamber)	Yellow colour; soft and fibrous pulp; over-ripe and flat taste

Table XXII gives the percentage of wastage of fruit stored at 45°F., 48° F. and 52°F.

TABLE XXII

Percentage of wastage in storage

45°F.		48°F.		52°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
67	7	48	3	49	10
72	9	55	10	53	14
80	14	64	19	59	19
..	..	69	37	64	32
..	..	78	71	77	78

It will be seen from the foregoing observations that the ' storage life ' was forty-nine days at 52°F., fifty-five days at 48°F. and seventy-four days at 45°F. The fruit could be kept for nine weeks at 45°F. and ripened satisfactorily at 68°F. or at room temperature. The limit of 10 per cent wastage reached on the seventy-fifth day of storage. This long period was, however, of no advantage due to the development of a dark colour of the pulp around the stone after nine weeks. The fruit stored at 48°F. for six weeks could be kept at room temperature for a week more. But the fruit which ripened in the storage chamber after fifty-five days at 48°F. and after forty-two days at 52°F. could not be kept at room temperature (80°F.-96°F.) for more than two days. The temperature of 45°F. was, therefore, found suitable for long storage.

Thana

The fruit required for the experiments was brought from Borivli in the Thana District. The fruit from this tract is called ' Ganvathi Alphonso ' in the Bombay market and is appreciated by many in preference to the fruit from the other tracts. The fruit was put into the cold chamber on the second day after picking.

The influence of the temperature of storage on the condition of the fruit is given in Table XXIII.

TABLE XXIII

Relation of temperature to ripening

Temperature of	Number of storage	Appearance of the fruit
43	84	Green
45	70	Just turning
48	50	Yellow and ripe
52	31	Yellow and ripe

Fruit stored at 43°F. The fruit remained in a hard and green condition for twelve weeks. The fruit after two or three weeks of storage did not ripen properly when transferred to 68°F. or to room temperature. After nine weeks of storage the tissues just near the stone assumed brown colour. There was no wastage for sixty-five days and the 10 per cent loss was noticed on the seventy-second day.

Fruit stored at 46°F. The fruit remained in a hard and green condition for weeks. Rotting was noticed after seven weeks and the ten per cent wastage occurred on the fifty-seventh day. A few fruits were removed at intervals during the storage period and kept at 68°F. for ripening. The taste and condition of the fruit so ripened were almost the same as those of the Poona Alphonso fruit described in Table XXI.

Fruit stored at 48°F. The fruit remained in a hard and green condition for four weeks when it began to change its colour. The fruit was completely ripe after fifty days of storage. On prolonged storage it became soft and the taste was flat. The ripe fruit did not keep well for more than two days when removed to room temperature. Rotting started after five weeks and the ten per cent wastage was observed on the forty-fifth day of storage.

Fruit stored at 62°F. The fruit began to change colour from the third week and was yellow after thirty-one days of storage. The fruit became soft and over-ripe after six weeks of storage. The ripe fruit did not keep in good condition for more than two days at room temperature. The ten per cent wastage took place after forty-nine days of storage when the fruit had become over-ripe.

The percentage of wastage of fruit stored at 45°, 48° and 52°F. at different periods during storage is given in Table XXIV.

TABLE XXIV

Percentage of wastage in storage

45°F.		48°F.		52°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
50	2	41	6	37	2
58	11	46	11	48	9
65	17	62	29	52	26
70	18	67	48	58	29
78	21	76	82	63	54
..	..	..	..	69	94

From the above results it will be observed that the ' storage life ' of fruit was forty-nine days at 52°F., forty-five days at 48°F. and fifty-seven days at 45°F. The ' storage life ' of fruit was longer at 52°F. than at 48°F. as the wastage was more at the latter temperature in the beginning. The fruit kept at 48°F. and 52°F. ripened after fifty and thirty-one days respectively. This ripe fruit did not keep in good condition for a long period as it soon got soft and over-ripe. The fruit could be kept in a hard and green condition for the whole length of the ' storage life ' at 45°F. and could be ripened properly at room temperature. The temperature of 45°F. was, therefore, found suitable for storage of the fruit for a long period.

Surat

The fruit for the trials was obtained from Bulsar which is an important place for Alphonso mango cultivation in the Surat District. The fruit was in transit for two days after picking. The influence of the storage temperature on the activity of ripening is shown in Table XXV.

TABLE XXV

Relation of temperature to ripening

Temperature of storage (°F.)	Number of days of storage	Appearance of the fruit
43	84	Green
45	73	Just turning
48	58	Yellow and ripe
52	42	Yellow and ripe

Fruit stored at 43°F. The fruit remained in a hard and green condition for twelve weeks. Within the first two weeks of storage some of the fruit showed slight browning. After three weeks of storage the fruit, still remaining quite green, did not ripen properly when transferred to 68°F. or to room temperature. After storage for nine weeks the pulp just near the stone assumed a brown colour which quickly became darker when the fruit was transferred to room temperature. There was no rotting until the sixtieth day of storage, but then the wastage was rapid, being 14 per cent on the sixty-sixth day.

Fruit stored at 46°F. The fruit remained in a hard and green condition for ten weeks. Some of the fruit started rotting after six weeks, the ten per cent loss being noticed after fifty-three days. At intervals during the storage period a few fruits were transferred to 68°F. for ripening. The taste and condition of the ripe fruit were nearly the same as those of the Poona Alphonso fruit given in Table XXI.

After nine weeks of storage the pulp of the fruit ripened at 68°F. was tough and showed dark brown colour near the stone.

Fruit stored at 48°F. The fruit remained in a hard and green condition for about five weeks and then commenced to change the colour and turned soft. It was yellow and ripe after fifty-eight days of storage. The ripe fruit did not keep well for more than two days when placed at room temperature. After nine weeks of storage the fruit began to get over-ripe and the pulp near the stone turned dark brown. There was no rotting for five weeks, but the ten per cent wastage was observed on the forty-third day of storage.

Fruit stored at 62°F. The fruit remained hard and green for three weeks only. Then it began to ripen and was fully yellow and ripe after forty-two days of storage. The ripe fruit could only be kept for two days in good condition at room temperature. The wastage was ten per cent on the thirty-sixth day of storage.

The percentage of wastage of fruit stored at 45°F, 48° F. and 52°F. at the different periods during storage is given in Table XXVI.

TABLE XXVI

Percentage of wastage in storage

45°F.		48°F.		52°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
52	9	37	6	36	10
60	18	42	9	42	20
65	20	58	34	46	25
73	33	63	54	52	40
..	..	73	85	57	63
..	..	..	..	63	87

From the observations described above it will be noticed that the ' storage life' of fruit was thirty-six days at 52°F., forty-three days at 48°F. and fifty-three days at 45°F. The fruit kept at 48°F. and 52°F. became ripe after fifty-eight and forty-two days respectively, i.e. a few days after the ten per cent loss was noticed. The fruit remained in green condition even longer than the full period of ' storage life ' at 45°F. The fruit ripened normally when placed at 68°F. and at room temperature and could be kept for a week at 68°F. The temperature of 45°F. was, therefore, suitable for long storage of the fruit.

Dharwar

The fruit for the trials was obtained from Dharwar. It was in transit for two days after picking. The fruit was stored at 45°, 48° and 52°F., the temperature of 43°F. being omitted. The influence of temperature on the ripening activity of the fruit is shown in Table XXVII.

TABLE XXVII

Relation of temperature to ripening

Temperature of storage (°F.)	Number of days of storage	Appearance of th e fruit
45	55	Hard and green
48	54	Green but turning soft
52	39	Yellowish green

Fruit stored at 45°F. The fruit generally remained in a hard and green condition. Some of the fruit, however, began to rot after five weeks of storage. The wastage reached ten per cent on the fortieth day. A few fruits were removed at intervals during the storage period and kept at 68°F. for ripening. The taste and condition of the fruit so ripened were not satisfactory.

Fruit stored at 48°F. The fruit remained in a hard and green condition for four weeks and then it began to get soft. Most of the fruit was green but almost soft at the end of eight weeks of storage. Such green and soft fruit did not ripen when exposed to 68°F., but started decaying.

Fruit stored at 62°F. The fruit remained green for three weeks only. The sound fruit turned yellowish green after six weeks of storage. The ten per cent wastage was noticed after two weeks of storage only.

The percentage of wastage of fruit stored at the three temperatures at different periods of storage is given in Table XXVIII.

TABLE XXVIII

Percentage of wastage in storage

45°F.		48°F.		52°F.	
Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage	Number of days of storage	Percentage of wastage
34	4	33	1	14	2
42	12	41	15	20	16
55	56	54	66	25	19
70	100	65	100	33	48
..	..	..	..	39	71
..	..	..	..	51	100

It can be seen from the above observations that the ' storage life ' was forty days at 45°F. The fruit after storage during this period at 45°F. ripened when transferred to 68°F., but the taste and condition of the pulp were not satisfactory. It appeared, therefore, that the fruit of Alphonso variety from Dharwar was poor in keeping quality as observed by Cheema and Dani [1934].

Comparison of the cold storage behaviour of the fruit from the different localities

The ' storage life ' of the fruit from the five localities at the storage temperatures of 45°F, 48° and 52°F. is given in Table XXIX for comparison.

TABLE XXIX

Relative storage life of fruit from different localities

Locality	' Storage life ' in number of days		
	45°F.	48°F.	52°F.
Ratnagiri	60	55	48
Poona	74	55	49
Thana	57	45	49
Surat	53	43	36
Dharwar	40	37	15

It is observed that the value for the ' storage life ' of the Poona fruit at 45°F. was distinctly higher than the values for the fruit from the other four localities. The Poona fruit also showed a different behaviour in regard to the extent of wastage. The values obtained for the percentage of wastage at 45°F. and 48°F. of fruit from the five localities have been represented graphically in Figs. 2 and 3. The curves of percentage of wastage at 45°F. of Poona and Dharwar Alphonso stood aloof on both the sides of the curves for the other localities. The curve of Ratnagiri Alphonso at 48°F. ran close to the curve of the Poona fruit at that temperature and the ' storage life ' of the fruit from the two localities was identical at 48°F. The ' storage life ' of the Thana and Surat fruit was lower at 45°F. and 48°F. than that of the fruit from Ratnagiri and Poona, the ' storage life ' of the Dharwar fruit at 45°F. being the lowest. The ' storage life ' at 52°F. of the fruit from Ratnagiri, Poona and Thana was practically the same, that of the Dharwar fruit being very short, i.e. fifteen days only.

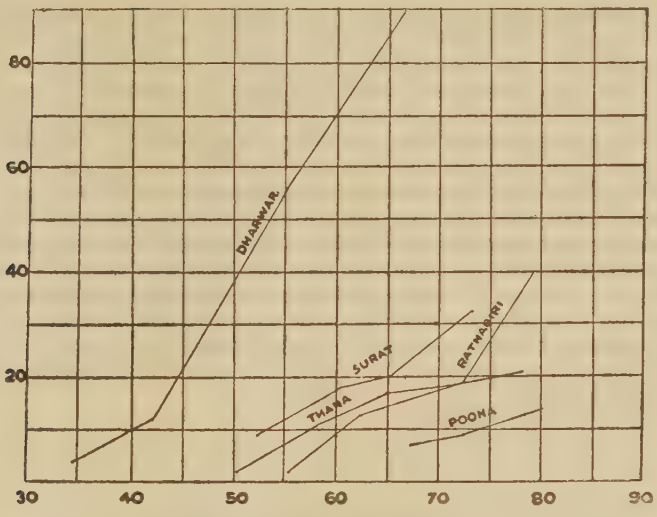


FIG. 2. PERCENTAGE OF WASTAGE IN STORAGE AT 45°F. OF ALPHONSO FRUIT FROM DIFFERENT LOCALITPES.

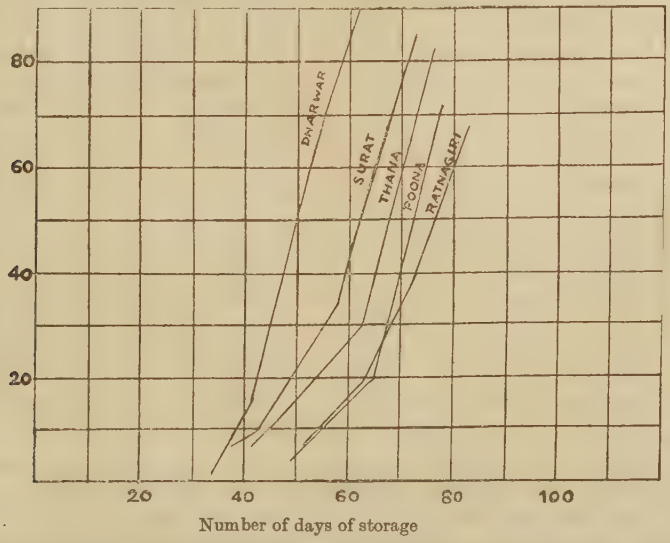


FIG. 3. PERCENTAGE OF WASTAGE IN STORAGE AT 45°F. OF ALPHONSO FRUIT FROM DIFFERENT LOCALITIES.

It was thought that the distinctly long ' storage life ' of Poona Alphonso fruit might be due to the freshness of the fruit at the time of keeping it in the cold chambers as the fruit was obtained from the adjacent gardens. The fruit from the other localities was in transit for about two days. An experiment was, therefore, arranged to test the effect of the freshness of fruit on the ' storage life '. Fresh fruit obtained from the adjacent gardens was divided into three lots. One lot was kept directly at 45°F. and the other two lots were packed in crates and kept at room temperature. The fruit of the second lot was unpacked after two days and that of the third lot after five days and kept at 45°F. There was no difference up to seven weeks in the condition of the fruit kept directly in the fresh condition and that kept after being left packed at room temperature for two days. After seven weeks, however, the rate of wastage of the fruit kept directly was found to be comparatively low. The fruit from the third lot unpacked after five days turned soft and was beginning to change colour. It turned brown when placed at 45°F.

The number of days after which the fruit from the five localities ripened is given in Table XXX for comparison.

TABLE XXX

Relative rate of ripening of fruit from different localities

Locality	Number of days required for ripening	
	48°F.	52°F.
Ratnagiri	75 (yellowish green only)	75 (pale yellow)
Poona	55	42
Thana	50	31
Surat	58	42
Dharwar	..	39 (yellowish green)

The fruit from Ratnagiri turned yellowish green only at 48°F. and became pale yellow at 52°F. after seventy-five days of storage when most of the fruit was wasted. The pale yellow fruit was hard, the ripening of the pulp was not complete and the pulp near the stone had turned dark brown. The ripening of the Dharwar fruit was not satisfactory and by the time the fruit turned yellowish green, the wastage had

reached 71 per cent. The fruit from Poona, Thana and Surat got fully ripe at 48°F. and 52°F. The fruit from Thana ripened a little earlier than the Poona and Surat fruit. In the case of the fruit from Poona, Thana and Surat, the period required for complete ripening at 48°F. was a little longer than the length of the ' storage life ' of the fruit at that temperature. The fruit from Ratnagiri was hard green at the end of the ' storage life ' at 48°F., i.e. after fifty-five days, and could be ripened properly at room temperature.

It was observed that in the case of the fruit from all the localities and in fruit of all the varieties tested in variety trials, the pulp near the stone either turned dark brown after nine weeks of storage at 43°, 45°, 48° and 52°F. or showed signs of brown colouration which later developed into dark brown when the fruit was placed at 68°F. and at room temperature.

Storage and ripening of the fruit after removal from the cold chambers

The following experiments were carried out on fruit of the Alphonso variety of ' B ' stage of maturity :

Effect of sudden cooling to 45°F. as compared to a gradual lowering of the temperature

It was thought that sudden cooling of the fruit from room temperature (90°F. average) to 45°F. may be attended with harmful results. Two trays of fruit were therefore, kept directly at 45°F. and two other trays were first kept in the air-lock space (at about 60°F.) for a day and then transferred to 45°F. The observations of this fruit showed that there was no difference in the storage behaviour of the two lots of fruit. The direct exposure to 45°F. did not show any chilling effect at all.

Effect of exposure to a temperature higher than the storage temperature on the subsequent ' storage life ' of the fruit

The fruit was kept in trays, each tray holding twenty-five fruits, at 45° and 48°F. Three trays were taken out from each chamber after thirty, forty and fifty days of storage and were kept at 68°F. for one, three, and five days. The trays were then transferred to the original temperature. It was found that the exposure to 68°F. for one and three days did not appreciably affect the subsequent ' storage life ' of the fruit. Five days' exposure at 68°F., however, was harmful. The fruit became soft and assumed a yellowish colour at 68°F. and the subsequent storage of this soft fruit at 45°F. and 48°F. was not very satisfactory. It may be safe to expose fruit, if necessary, to a temperature higher than the storage temperature for a short time only, so that the fruit still remained hard and green.

Effect of the length of the storage period on the rate of ripening and the quality of the fruit when transferred to 68°F. or to room temperature

At intervals during the storage period some of the fruit was removed to 68°F. and to room temperature and kept in trays to ripen. The number of days required

for ripening is given in Table XXXI from which it will be noticed that the rate of ripening of the cold-stored fruit showed down as the period of storage advanced :

TABLE XXXI

Rate of ripening of fruit after cold storage

Number of days of storage	Temperature of storage	Number of days required for ripening	
		68°F.	Room temperature (80°-96°F.)
30	45°F.	6	5
30	48°F.	6	5
40	45°F.	8	7
40	48°F.	7	7
50	45°F.	10	10
50	48°F.	10	10
65	45°F.	10	10
65	48°F.	10	10

The chemical analyses of the fruit ripened at 68°F. after different periods of storage at 45°F. and 48°F. showed that the percentage of total sugars was quite normal up to sixty days of storage but decreased after sixty-five days at 45°F. The percentage of total sugars in fruit from 45°F. was higher than that in fruit from 48°F. and also than in the ordinary ripe fruit (12·91 per cent) which agreed well with the results described later. The percentage of total sugars in the fruit ripened at 68°F. after varying periods of storage is given in Table XXXII.

TABLE XXXII

Percentage of total sugars in fruit ripened after cold storage

Number of days of storage	Percentage of total sugars	
	45°F.	48°F.
40	14·6	13·6
50	14·0	13·9
60	15·3	13·5
65	8·3	..

Effect of different temperatures on the keeping quality of the fruit ripened after cold storage

It was found that the fruit ripened after cold storage could be kept in a good condition for about a week at 68°F. and for four days at room temperature. If kept longer, either it rotted or was spoilt by the development of brown pulp around the stone. The appearance of brown pulp was more marked in the case of the fruit after fifty and sixty-five days of storage.

It was observed that the fruit ripened after cold storage did not turn brown when kept at the lower temperatures. It was possible, therefore, to keep the fruit thus ripened in good condition for about two weeks at 45°F. and 48°F.

Effect of temperatures higher than the room temperature on the ripening of the fruit after cold storage

The fruit removed from the cold chambers was kept in two incubators maintained at 100°F. and 110°F. by means of electric lamps. The humidity was not controlled. It was found that the fruit kept at these temperatures shrivelled, assumed a pale yellow colour and rapidly developed a brown colour of the pulp around the stone. The effect on the ordinary fruit without cold storage was also similar, with the exception of the browning of the pulp.

Comparison of the cold-stored fruit ripened in boxes and in open trays

It has been observed that as a result of long cold storage, the peculiar aroma of the Alphonso fruit was affected to some extent. It was thought that by ripening the fruit in boxes instead of in trays the characteristic aroma of the fruit would be revived. The fruit stored at 45°F. was taken out and kept for ripening in trays as well as in boxes. It was found that though there was no appreciable difference in the number of days required for ripening, the aroma appeared to develop better in the case of the fruit ripened in boxes than in the case of the fruit ripened in trays.

Selection of Alphonso fruit for cold storage

It has been shown that the ' B ' stage of maturity (green and hard, but mature) is the proper stage for cold storage. In the cold storage trials the fruit showing any blemish or bruise was scrupulously rejected. Further experiments were, therefore, arranged to find the effects of blemish or bruise on the green Alphonso fruit in cold storage. The fruit rejected from the trials at the time of the selection on account of these defects was stored at 45°F. and 48°F. It was found that the fruit did not develop any fungal growth but remained in the same condition and ripened when removed to 68°F. The pulp at the point of the blemish or the injury did not soften but remained hard and assumed only a pale yellow colour. Of course, the fruit did not keep for a long time after it was ripe. In cases where there was a definite sharp cut, the wound was found to have practically healed up to some extent. The injured or blemished fruit of varieties like Banganpalli, Fazri White, etc. which are less acidic in green condition rotted very quickly.

The question of the size of the fruit and of leaving a portion of the stalk on the fruit was also investigated.

Size of the fruit

The observations during the course of these investigations did not bring out any marked difference between the fruit of different sizes. It was the stage of maturity which was very important. Both the big and the small fruit of the same stage of maturity required an equal period for ripening at 68°F. It will also be seen from the figures of wastage (Table XXXIII) that there was not a great difference in between the fruit of the two sizes ripened at 68°F.

TABLE XXXIII

Relative percentage of wastage of big and small fruit at 58°F.

Number of days of storage	Percentage of wastage	
	Big (average weight, 300 gm.)	Small (average weight, 180 gm.)
19	0	8
21	14	16
28	56	45

The relative loss in weight during storage at 48°F. and 68°F. of the two sizes of fruit of the same stage of maturity was found out. The values obtained are given in Table XXXIV.

TABLE XXXIV

Relative loss in weight during storage of big and small fruit

Number of days of storage	Percentage loss in weight			
	48°F.		68°F.	
	Big	Small	Big	Small
4	..	..	1·5	2·0
8	1·6	1·5	3·4	4·2
12	..	..	5·4	6·7
16	3·0	2·9	7·1	8·7
20	..	..	8·6	10·5
25	4·5	4·6	10·2	..
33	5·9	6·0	..	..
41	7·2	7·2	..	..

The rate of loss in weight at 48°F. was nearly equal in both the sizes of fruit at 68°F., however, the percentage loss in weight in the case of the small fruit was higher than in the case of the big fruit. The average ratio of the percentage loss in weight in small fruit to the percentage loss in weight in big fruit was found to be 1·252. This ratio was observed to be nearly equal to the ratio of the surface area of the skin per 100 gm. of small fruit to the surface area of the skin per 100 gm. of big fruit. This was determined by peeling off the skin of the fruit of known weight and measuring its area. The ratio was found to be 1·266. The loss in weight during storage is partly due to the evaporation of water from the surface of the fruit and partly to the respiration processes. The rate of evaporation of water from the fruit is expected to be low at 48°F. The higher loss in small fruit at 68°F., therefore, appears to be due to the greater evaporation of water from small fruit which has a relatively larger surface area.

Fruit with and without stalk

It is a belief that the fruit plucked with the stalk intact lasts longer. The experiments of Burns and Prayag [1920] showed, however, that the cutting of the mango fruit from the tree with a piece of stalk made no difference to its keeping qualities. They noticed that the stalk withered and fell off a few days after plucking. They found it desirable, however, that the fruit should have an inch of stalk to prevent the oozing out of sap all over the skin of the fruit and thereby spoiling its appearance.

It has been found during these investigations that the sap which solidifies on the skin on exposure to the atmospheric temperature for a short time did not affect the ripening of the fruit at 60°F. and 68°F., but its presence led to the appearance of green and brown spots when stored at the lower temperatures. It has also been found that if the stalk portion was removed carefully by holding the fruit with the stalk-end downwards so as to prevent the sap running over the skin, the keeping quality remained unaffected.

In the storage and transport at ordinary temperature the stalk withers as the fruit ripens and falls off. If it gets broken off, the sap oozes out and is solidified quickly. The appearance of the fruit only is thus somewhat spoilt by the presence of the semi-transparent gummy residue. But in cold storage at 45°F. and 48°F. the fruit remains green and does not ripen for a long period. It is possible that the stalk may get broken off in handling the fruit and the sap would rush out and flow on the fruit which, in the course of time, would turn the fruit brown.

An experiment in connection with the storage behaviour of fruit with and without stalk at 68°F. showed that the fruit with stalk exhibited a higher percentage of stem-end rot as could be seen from the results given in Table XXXV. It appears that the sap which is a corrosive substance acts as a mild germicide. An analysis of the gum showed that it contains an oil of the terpene series along with other gummy material.

TABLE XXXV

Relative percentage of stem-end rot in fruit with and without stalk

Number of days of storage	Percentage of stem-end rot	
	Fruit with stalk	Fruit without stalk
12	9	5
16	9	17
19	14	17
25	18	16
30	25	32

Effect of moisture on the fruit

Experiments were carried out to determine the effect of moisture on the fruit on the ' storage life '. These experiments were undertaken with a veiw to find the effect of rain preceding picking of the fruit, on the storage behaviour. For this purpose, fruit was either kept in water for a short time or water was sprayed on it for two to four hours. It was found that the presence of water on the skin of the fruit had a deleterious effect. The fruit when carefully dried could be kept in a better condition.

PACKING OF ALPHONSO FRUIT FOR COLD STORAGE

Effect of wrapping

Banerjee, Karmarkar and Row [1934] found that the wrapping of the fruit with tissue paper had no beneficial effect in cold storage. The measurements of loss in weight and storage data obtained by Wardlaw and Leonard [1936] indicated the need for wrapping fruit to curtail water losses. Tin foil, waxed paper and cellophane wrappers gave almost comparable results. It was found in these investigations that the rotting of the fruit was not contagious but that it depended on the physiological condition of the fruit. The effect of different wrappers was, however, investigated in order to keep the sound fruit individually separated from the rotting fruit and also to reduce wastage.

Three lots of fruit wrapped in white tissue paper, red tissue paper and waxed paper, were kept at 48°F. along with unwrapped fruit for comparison. The fruit

was examined after forty-two and seventy days of storage. The results of the examinations are shown in Table XXXVI.

TABLE XXXVI

Effect of different wrappers

Number of days of storage	No wrapping		White tissue		Red tissue		Waxed paper	
	Good fruit (per cent)	Wastage (per cent)	Good fruit (per cent)	Wastage (per cent)	Good fruit (per cent)	Wastage (per cent)	Good fruit (per cent)	Wastage (per cent)
42	92	8	92	8	100 (development of brown specks)	0	84	16
70	16	84	4	96	29	71	0	100

The fruit after forty-two days of storage appeared quite normal except that in the case of red tissue paper brown spotting was observed and in the case of waxed paper partial browning of the skin, accompanied by a fermenting odour, was noticed. The fruit after being unwrapped was kept at 68°F. for ripening. Most of the wastage observed was due to lateral rot. Table XXXVII shows the percentage of wastage of the fruit at 68°F.

TABLE XXXVII

Relative percentage of wastage in fruit wrapped with different kinds of paper

Number of days of storage	Percentage of wastage		
	White tissue paper	Red tissue paper	Waxed paper
4	48	33	71
7	64	58	90
11	72	66	90

The fruit without any wrapping did not show an appreciable wastage but ripened normally.

The above results clearly showed that though the fruit appeared unaffected on unwrapping after forty-two days of storage at 48°F., the wrapping definitely vitiated its ripening power and this effect was the most marked in the case of waxed paper.

Further experiments showed that wrapping with tissue paper had no bad effect on fruit stored at 68°F. or at room temperature, as it ripened normally and kept well. The fruit wrapped in waxed paper and also in cellophane paper was adversely affected.

Effect of different packing materials

Experiments were conducted to find out a suitable packing material. Ordinarily the nature of the packing material used in the packages for transport varies with the locality. The fruit from the Ratnagiri tract is usually packed with rice straw. Paper sheets are placed above and below the layer of fruit in order to keep it clean. The fruit from Thana tract is usually packed with *karanj* (*Pongamia glabra*) leaves and sometimes even with mango leaves. The fruit for the experimental export to the United Kingdom was packed with fine wood-wool. The study of the effect of packing the fruit in saw-dust was also included in these investigations.

Both the bamboo baskets and wooden crates were used in packing fruit. The bamboo baskets used in these experiments held about fifty fruits. The baskets usually used in the market hold about eighty to a hundred fruits. The crates were of the size of 24 in. × 12 in. × 12 in. Cardboard boxes of the size of 16 in. × 12 in. × 6 in. were also tried. The trials with cardboard boxes were made for the use of a light packing material.

The packages were kept at 45° and 48°F. Half the number of packages were opened after forty days of storage and the condition of the fruit was inspected while the remaining were opened and examined after sixty-five days. The results of these examinations are given in Tables XXXVIII and XXXIX.

TABLE XXXVIII

Percentage of wastage in fruit packed with different kinds of packing material

Packing material and container	40 days of storage at 45°F.		65 days of storage at 45°F.	
	Good fruit (per cent)	Wastage (per cent)	Good fruit (per cent)	Wastage (per cent)
Saw-dust in cardboard box	97	3	47	53
Mango leaves in bamboo basket	26	74	0	100
Karanj leaves in bamboo basket	0	100	0	100
Rice straw in bamboo basket	100	0	64	36
Wood-wool in wooden crate	96	4	25	75
Control in wooden crate without any packing material	100	0	80	20

TABLE XXXIX

Percentage of wastage in fruit packed with different kinds of packing material

Packing material and container	40 days of storage at 48°F.		65 days of storage at 48°F.	
	Good fruit (per cent)	Wastage (per cent)	Good fruit (per cent)	Wastage (per cent)
Saw-dust in cardboard box	88	12	20	80
Mango leaves in bamboo basket	44	56	0	100
Karanj leaves in bamboo basket	0	100	0	100
Rice straw in bamboo basket	96	4	38	62
Rice straw in wooden crate	70	30	..	..
Wood-wool in wooden crate	77	23	0	100
Control in wooden crate without any packing material	94	6	..	..

Saw-dust. The fruit found in good condition on examination of the cardboard boxes was kept at 68°F. to study the subsequent ripening. The fruit began to change colour as ripening commenced, but at the same time there was a development of dark brown patches on the skin, and by the time the fruit was soft and ripe, it was almost rotten.

Mango and karanj *leaves.* The leaves turned soft and brown and there was a beginning of fungal growth after forty days of storage. The leaves and the inside of the baskets were overgrown with fungus after sixty-five days. The fruit developed dark brown spots on the skin. Fungi belonging to the species *Pestalozzia* and *Alternaria* were identified.

Rice straw. The straw remained dry. The fruit showed slight marks due to the pressing of straw. There was a development of fungus in crates packed with rice straw after sixty-five days of storage while no fungal growth was observed in the case of baskets.

Wood-wool. There were definite impressions of wood-wool on the fruit. There were no marks on fruit individually wrapped in tissue paper and then packed in wood-wool, but the fruit deteriorated.

Control. The fruit was packed in crates without any packing material and arranged in layers one above the other. The fruit did not appear to have been pressed at all. The appearance was quite sound.

The sound fruit from the rice straw and wood-wool packings, examined after forty days of storage, was kept at 68°F. for ripening. The fruit from the control

experiments ripened quite normally at 68°F. and did not show any appreciable wastage. The fruit from the rice straw and wood-wool packings showed a considerable wastage during the ripening period (Table XL).

TABLE XL

Percentage of wastage in fruit kept at 68°F. after unpacking

Number of days at 68°F.	Percentage of wastage		
	Wood-wool (crate)	Rice straw (crate)	Rice straw (basket)
4	21	43	13
7	24	57	21
11	47	86	33
14	55	88	48

The results clearly indicated that the presence of any packing material adversely affected the fruit in all cases. Mango and *karanj* leaves and saw-dust were quite unsuitable packing materials for cold storage. Rice straw and wood-wool did not appear to affect the fruit while in cold storage but they certainly impaired the ripening activity. It has also been found that the fruit without any wrapping kept the best. It is advisable, therefore, to pack the fruit in crates, as they are more easy to handle and to store, with either rice straw or wood-wool, just sufficient to avoid any bruising of the fruit.

The change in volume of green fruit on ripening has been followed. It was found that there was a definite decrease in volume (about ten per cent) as the fruit ripened and consequently a rise in the specific gravity value. But as the green fruit does not ripen at 45°F. or 48°F., there is no change in the volume and thus there is no fear of the fruit sinking down in the crate after it has been carefully packed.

The use of the least packing material is also advantageous in other ways. The temperature of the fruit in a crate with the minimum packing material could be brought down much more quickly than in the case of fruit packed tightly with a large quantity of rice straw or wood-wool. Besides, it has been observed that the fruit, when exposed even for a short time to a temperature of 40°F. or lower in order to accelerate the rate of cooling in tightly packed crates, is chilled and cannot be ripened properly.

Pre-cooling

The time required by the fruit to attain the temperature of the storage chamber after storing was determined. The fruit of uniform size was selected for this purpose. Two holes, about two inches deep, were made near the stalk-end with a cork-borer

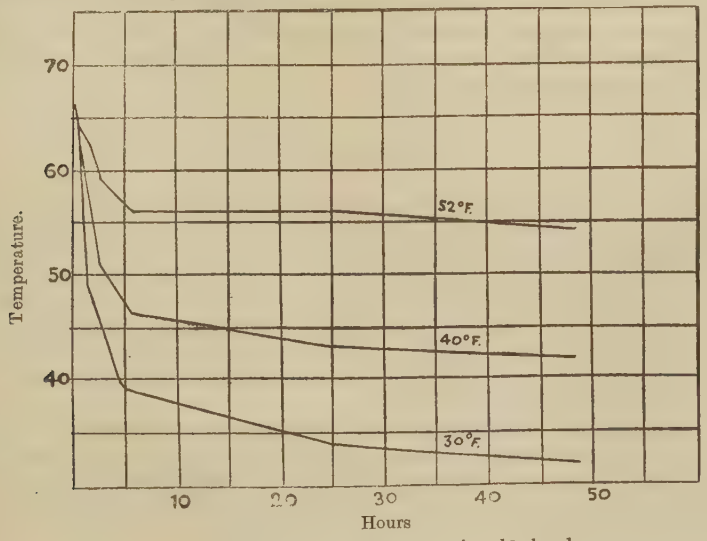
along each flat side of the stone. The temperature was recorded immediately after boring the holes by inserting a closely fitting thermometer. The temperature recorded from both the holes was found to be the same. The rate of fall in the temperature of the fruit kept at different temperatures is given in Table XLI.

TABLE XLI

Rate of fall in temperature of fruit in the storage chambers

Temperature of storage chamber	Initial temperature F.	Time in hours						
		½	1½	2½	4½	5½	24	48
		Temperature in °F.						
30°F,	66	61	49	45	40	39	34	32
40°F.	66	62	55	51	48	46	43	42
52°F.	66	64	62	59	57	56	56	54

The results are shown graphically in Fig. 4. It will be seen that the fruit kept at the different temperatures required about forty-eight hours to attain the temperature of the storage chamber, even though the fall in temperature was rapid in the beginning. The fruit was placed in open trays. The fruit packed in crates would naturally require a longer time. It is not convenient to spread the fruit in the chamber before packing it in crates.



[FIG. 4. Rate of fall in temperature in cold chambers

It was presumed that fruit could be cooled down more rapidly to the required temperature by placing it first at temperatures lower than the storage temperature. It was observed that by doing so it required about three hours at 30°F. and six hours at 40°F. to lower the temperature of the fruit from 90°F. to the storage temperature of 48°F. The shorter time required at 30°F. to lower the temperature was considered an advantage. But when the fruit was placed at 30°F. only for three hours before storing it at 48°F., it was found that the exposure at 30°F. for even such a short period chilled the fruit.

Suitable kind of package for cold storage

The cardboard boxes used in one of the experiments described earlier were found to be unsuitable for cold storage as the high humidity in the storage chambers made the paper soft and altered the shape and strength of the boxes. The boxes were found to be satisfactory for room temperature where the humidity is usually low. There was no appreciable difference between bamboo baskets and wooden crates. The bamboo baskets are flexible and rather difficult to handle in cold store properly. The wooden crates are easy to handle and also more economical.

Small crates of the size of 18 in. × 10 in. × 4½ in., holding a dozen of Alphonso fruit which were used for export to the United Kingdom were found suitable by Cheema and Dani [1934]. Twelve fruits, individually wrapped in white tissue paper, were kept in each tray and packed with wood-wool. The crates were stored at 45°F. and 48°F. On inspection of these crates after six and nine weeks of storage it was found that the fruit remained in a better condition than that packed in the same way in bigger crates of the size of 24 in. × 12 in. × 12 in., each holding about a hundred fruits. The results, however, have shown that the fruit packed in the bigger crates without any wrapping and with the minimum of packing material kept in good condition without an appreciable wastage. A crate of the above size, therefore, seems suitable for commercial cold storage.

Nature of wastage

Chilling

It has been observed that ripe yellow fruit (eating maturity) of all the varieties except those of Kolanka Goa, Fazri Zafrani and Fernandez varieties, was rendered unsuitable for cold storage, due to the change of the yellow colour to brown soon after keeping it in the cold chambers at temperatures from 30° to 52°F. In all cases only the good colour of the skin was lost. The pulp of the fruit remained unaffected until the fruit developed a fungal growth or a physiological break-down. This chilling effect was also marked in some fruit of 'C' stage of maturity where the green colour of the skin showed a lighter shade.

The symptoms of chilling in the case of green and hard fruit of 'B' and 'C' stages of maturity depended on the temperature of storage and on the variety. The fruit of all the varieties was chilled at 30°F. At this temperature the colour of the skin turned boiled green and the fruit decayed immediately after it was exposed to 68°F. or to room temperature. The fruit at 35°F. developed well marked pits on the

skin and failed to ripen when removed to 68°F. The chilling at 40°F. and 43°F. was not so marked to the naked eye as the fruit appeared to keep well at these temperatures. But the fruit in most cases failed to ripen at 68°F., and in the case of the fruit of Alphonso, Pyree, Fazri Zafrani and other varieties, the ripening was found to be irregular, due to the development of large granular portions in the flesh. The fruit of Alphonso, Pyree, Peter and Cawasjee Patel varieties did not show any chilling effects at 45°F. and 52°F., the ripening of green fruit transferred to 68°F. being quite normal. A feature of the fruit ripened at 68°F. after cold storage at 45°F., 48°F. and 52°F. was the softness of the skin and the resistance to chilling when placed at low temperatures. The peel could also be easily separated from the flesh as is observed by Wardlaw and Leonard [1936]. The failure to ripen at 68°F. of green fruit of varieties like Black Andrews, Fazri Zafrani, Shendrya and others, which kept in good condition for certain periods at temperatures from 45°F. to 52°F., could be attributed to chilling. Wardlaw and Leonard [1936] found that the majority of West Indian varieties tested by them showed definite chilling effects at temperatures of 40°F. and 45°F. and, with a few exceptions, chilling effects were not observed in fruit stored at 50°F.

Physiological breakdown

In addition to the losses due to chilling and its after-effects, the fruit showed a browning of the tissues around the stone generally after nine weeks of storage at 45°F. and 48°F. The browning developed rapidly when the fruit was kept for ripening at 68°F. or at room temperature and a considerable part of the pulp was affected. The pulp still remaining yellow tasted insipid. Such browning of the pulp was also noticed in fruit which became over-ripe at 68°F. and at room temperature.

Fungal rotting

Cheema and Dani [1934] have reported that samples of rotted fruit showed either a Phomopsis stem-end rot or a Dothiorella rot, also apparently originating from the point of attachment of the fruit to its stem. One only of the seven fruits examined showed the presence of *Gloeosporium mangiferae* P. Henn. Palacios and Karkare [1935] reported that the rot need not necessarily start from the stalk-end and that the attacking fungus was quite common to all Indian fruits. Banerjee, Karmarkar and Row [1934] observed that the skin of the mango harbours a large number of fungi and bacteria, among which an aerobic bacterium and a fungus most prominently act as agents, causing the decay of the fruit.

In the ordinary course of ripening, the infections present on the fruit lie dormant until the fruit begins to pass from the stage of 'eating maturity' to the stage of over-ripeness and subsequent decay. In fact, the commencement of rotting of normally ripe fruit is an indication of the physiological changes going on in the fruit which render the fruit less resistant to fungal attack.

The cause of decay in stem-end rot, lateral rot, 'brown patches' and 'watery rot' has been found to be a species of *Gloeosporium*. This fungus is present on the fruit as latent infection and the development of the different kinds of rot starts only

when there is a decrease in resistance to its growth at the different temperatures of storage in the cold chambers.

Experiments on the effect of different treatments in retarding the development of 'brown patches' in the case of Suwarnarekha and Banganpalli fruit were attended with negative results. Banerjee, Karmarkar and Row [1934] carried out some experiments on the effect of treating fruit with disinfectant solutions, such as potassium permanganate, formalin, phenol, etc., of blanching fruit in a sodium chloride solution and of giving a thin coating of wax on the skin of the fruit. None of these treatments was found to be of any help in lengthening the storage life of the fruit. Palacios and Karkare [1935] found that mere surface-sterilization was not sufficient to prevent rotting.

The observation, that the mango harbours different micro-organisms on its surface and underneath the skin and that they function as latent infections at the time of decreased resistance, is strengthened by the repeated observations in the course of these experiments that the decay mainly depends on the physiological condition of the fruit. A sound fruit, in ripe condition, could not be made to rot simply by keeping it in close contact with a rotting fruit. It was necessary for the fruit to reach a certain physiological condition which offered little resistance to the growth of the organism present on the fruit itself.

Chemical composition of the fruit of different varieties of mango

Efforts have been made by various investigators to discover a relation of the chemical composition of fruit to the 'storage life' and susceptibility to fungal invasion. Most of the work in this direction has been done on apples [*Imperial Horticultural Conference Proceedings*, 1930, and *Food Investigation Board Reports*, 1928 and 1929]. It has been shown that high acid content and low nitrogen content are associated with a low rate of fungal invasion in apples. The investigations on the relationship of acid and sugar concentrations to the growth of fungi to which apples showed varying degrees of resistance, indicated that the rate of growth of fungi was inversely related to acid concentration.

It has been observed that the fruit of the different varieties of mango showed a different behaviour at the various temperatures of storage and also, the length of the 'storage life' varied greatly. Further, the fruit of some of the varieties, like Banganpalli or Fazri White, were more inclined to rot than the fruit of Alphonso or Cawasjee Patel varieties. An examination of the thickness of the skin of the fruit of different varieties did not show any relation of the thickness of the skin to the storage period.

The chemical analysis of the pulp of the fruit of the different varieties of mango both in the green and ripe condition were carried out. Burns and Prayag in their book on mango [1920] have given the chemical composition of the juice of fresh Alphonso mango. Sahasrabuddhe [1925] analysed the ripe fruit of Alphonso and Pyree varieties of mango. Banerjee, Karmarkar and Row [1934] have studied the

chemical changes in mangoes during storage. Bijhouwer and Donath [1935-36] analysed ripe fruit of the main mango varieties of Java as well as the fruit of an Alphonso tree growing there. Wardlaw and Leonard [1936] have followed the changes in acidity in West Indian mangoes during development and ripening and also in cold storage. Their results are in general conformity with the results obtained by Banerjee and his co-workers [1934]. The vitamin content of the pulp of three varieties of mango has been examined by Perry and Zilva [1933] to whom the fruit was exported from Bombay in the Purser's Cool Room. The results showed that the pulp of the Alphonso fruit was one of the most potent sources of vitamin C and also contained vitamin A in quantities similar to that possessed by butter.

Methods of estimation

Sampling. In order to get a representative sample, ten fruits were taken at random from a lot of selected fruit of one stage of maturity. After peeling off the skin the pulp from the middle portion of the fruit only was used for the sample. The pulp was cut into pieces which were mixed together thoroughly.

Water. About 20 gm. of the sample was weighed out accurately into a small flat-bottomed glass dish and dried in an electrically heated steam oven for four days.

Acidity. Samples for the determination of acidity were preserved in alcohol. About 20 gm. of the sample was weighed out into a Kelly bottle (400 c. c. capacity) and 100 c. c. of hot neutral ninety-six per cent alcohol added. The alcohol was then brought to boiling in a water-bath. The bottle was taken out and immediately closed with a waxed cork.

At the time of the estimation, the contents of the bottle were carefully poured out into a beaker and the inside of the bottle washed with alcohol, the washings being added to the contents of the beaker. The mixture was then strained through muslin cloth. The pulp remaining on the muslin strainer was transferred to a small mortar and macerated with warm dilute alcohol. The macerated pulp was again strained through muslin and the filtrate added to the original extract. The total volume of the extract was then made up to 250 c. c. The acidity was determined with aliquots of the extract by titration with decinormal solution of sodium hydroxide using phenolphthalein as indicator. The amount of acid present was calculated in terms of malic acid and expressed as percentage of fresh weight of the pulp.

Sugars. The samples for the estimation of sugars were also preserved in alcohol like the samples for acidity. About 50 gm. of the sample was used. A little calcium carbonate was added to neutralize the acids present to prevent an inversion of the sugars. At the time of the estimation of sugars the alcoholic extract was decanted and the solid pulp thoroughly extracted with alcohol in a Soxhlet. The excess of alcohol was removed from the combined extracts by distillation on a water-bath under reduced pressure. The alcohol-free extract was taken out from the distilling flask and clarified by using dialysed iron. The clear extract was then made up to 500 c. c. Aliquots of the final extract were used for the determination of reducing sugars.

For the determination of total and non-reducing sugars 50 c. c. of the extract was hydrolysed under reflux with 10 per cent citric acid solution on a water-bath for half an hour. The extract was then cooled, neutralized with sodium hydroxide solution and the volume made up to 100 c. c. Aliquots were used for the determinations. Lane and Eyon's methylene blue method was employed.

Total nitrogen. About 20 gm. of the sample was weighed out accurately and put on a filter paper, the pulp moistened with dilute sulphuric acid and then dried in a steam oven. The dried sample was used for the determination of the total nitrogen. A blank was done with a filter paper. The total nitrogen was expressed as percentage of the fresh weight of the pulp.

The results of the analyses of samples of both the green and ripe fruit of the different varieties of mango are given in Tables XLII—XLV.

Table XLII

Percentage of water

Variety	Percentage of water	
	Green	Ripe
1. Peter	81·70	80·51
2. Suwarnarekha	84·08	80·85
3. Jahangir	81·47	18·64
4. Banganpalli	80·37	80·47
5. Kolanka Goa	83·93	83·40
6. Black Andrews	82·71	78·60
7. Langra	76·60	77·13
8. Jardalu	80·78	80·74
9. Hemsagar	75·43	75·54
10. Fazri Zafrani	84·49	82·71
11. Calcutta Amin	82·12	82·61
12. Fazri White	81·44	78·99
13. Naspati	80·22	81·13
14. Sali Banda	81·06	81·54
15. Pyree	83·76	82·53
16. Shendrya	77·03	78·79
17. Cawasjee Patel	83·24	84·01
18. Batli	82·54	81·91
19. Borsha	81·02	79·69
20. Fernandez	80·04	79·56
21. Alphonso (Ratnagiri)	80·05	79·95
,, (Poona)	80·61	79·12
,, (Thana)	79·43	78·45
,, (Surat)	80·62	79·21
,, (Dharwar)	79·16	78·10
22. Raival (country variety)	83·41	83·24

TABLE XLIII

Percentage of total nitrogen on fresh-weight basis

Variety	Percentage of total nitrogen.	
	Green	Ripe
1. Peter	0·152	0·036
2. Suwarnarekha	0·058	0·079
3. Jahangir	..	0·066
4. Banganpalli	0·109	0·127
5. Kolanka Goa	0·064	0·055
6. Black Andrews	0·106	0·053
7. Langra	0·132	0·128
8. Jardalu	..	0·102
9. Hemsagar	..	0·088
10. Fazri Zafrani	0·052	0·056
11. Calcutta Amin	0·080	0·078
12. Fazri White	0·116	0·157
13. Naspati	0·130	0·150
14. Sali Banda	0·109	0·070
15. Pyree	0·116	0·096
16. Shendrya	0·102	0·132
17. Cawasjee Patel	0·064	0·072
18. Batli	0·073	0·086
19. Borsha	0·103	0·113
20. Fernandez	0·082	0·084
21. Alphonso (Ratnagiri)	0·110	0·120
,, (Poona)	0·111	0·131
,, (Thana)	0·101	0·114
,, (Surat)	0·125	0·143
,, (Dharwar)	0·105	0·134
22. Raival (country variety)	..	0·094

TABLE XLIV

Percentage of acidity in terms of malic acid on fresh-weight basis

Variety	Percentage of acidity	
	Green	Ripe
1. Peter	1·44	0·27
2. Suwarnarekha	1·50	0·30
3. Jahangir	..	0·29
4. Banganpalli	0·80	0·20
5. Kolanka Goa	1·27	0·36
6. Black Andrews	1·02	0·29
7. Langra	0·67	0·22
8. Jardalu	..	0·20
9. Hemsagar	..	0·22
10. Fazri Zafrani	1·63	0·56
11. Calcutta Amin	1·88	0·33
12. Fazri White	0·94	0·22
13. Naspati	0·87	0·33
14. Sali Banda	1·74	0·54
15. Pyree	2·75	0·40
16. Shendrya	3·66	0·24
17. Cawasjee Patel	3·11	0·18
18. Batli	1·92	0·31
19. Fernandez	1·35	0·32
20. Borsha	2·38	0·43
21. Alphonso (Ratnagiri)	2·54	0·18
,, (Poona)	2·54	0·27
,, (Thana)	3·11	0·37
,, (Surat)	2·39	0·25
,, (Dharwar)	2·06	0·54
22. Raival (country variety)	..	0·42

TABLE XLV

Percentage of total, reducing and non-reducing sugars on fresh-weight basis

Variety	Green			Ripe		
	Total	Reducing	Non-reducing	Total	Reducing	Non-reducing
1. Peter	6·63	4·03	2·60	12·10	3·91	8·19
2. Suwarnarekha	4·50	3·43	1·07	14·02	3·98	10·04
3. Jahangir	..	..	..	13·45	4·06	9·39
4. Banganpalli	8·10	4·16	3·94	13·90	2·80	11·10
5. Kolanka Goa	9·45	4·15	5·30	12·68	4·27	8·41
6. Black Andrews	4·87	2·63	2·24	15·89	3·30	12·59
7. Langra	5·97	3·39	2·58	16·17	2·36	13·81
8. Jardalu	..	..	..	13·60	3·83	9·77
9. Hemsagar	..	..	..	16·80	3·45	13·35
10. Fazri Zafrani	4·35	2·31	2·04	11·85	2·48	9·37
11. Calcutta Amin	4·57	1·75	2·82	12·72	2·30	10·42
12. Fazri White	5·45	1·85	3·60	15·34	1·67	13·67
13. Naspati	7·46	1·67	5·79	13·15	1·62	11·43
14. Safi Banda	6·26	2·60	3·66	13·36	4·83	8·53
15. Pyree	2·26	1·35	0·91	12·27	2·12	10·15
16. Shendrya	1·45	0·92	0·53	13·60	1·40	12·20
17. Cawasjee Patel	1·80	1·32	0·48	11·20	2·31	8·89
18. Batli	3·53	1·95	1·58	13·22	2·22	11·00
19. Borsha	6·60	2·82	3·78	13·59	2·48	11·11
20. Fernandez	5·78	1·91	3·87	13·37	2·08	11·29
21. Alphonso (Ratnagiri)	2·54	1·41	1·13	12·91	3·23	9·68
Alphonso (Poona)	2·46	1·48	0·98	13·14	1·82	11·32
„ (Thana)	2·00	1·21	0·79	15·56	2·64	12·92
„ (Surat)	2·25	1·08	1·17	15·61	2·07	13·54
„ (Dharwar)	..	..	..	15·05	2·68	12·37
22. Raival (country variety)	..	..	..	11·90	2·22	9·68

Percentage of water. The range of percentage of water varied from 75·43 in green Hemsagar fruit to 84·49 in green Fazri Zafrani fruit, the amount of water in green fruit of the other varieties being within this range. The percentage of water in green and ripe fruit did not show a great difference. In some cases the difference was not appreciable. In others the difference was less than 1·5 per cent. The common tendency in the case of important varieties appeared to be to have a slightly higher percentage of water in green fruit as compared with ripe fruit, a condition which seems possible as some water must always be lost by transpiration during the course of ripening. It was only in the fruit of Suwarnarekha, Black Andrews and Fazri White varieties that the percentage of water was appreciably higher in green fruit, being 3·23, 4·11 and 2·45 per cent more than that in the ripe fruit repectively.

Total nitrogen. The percentage of total nitrogen in the fruit of the different varieties is expressed in terms of the fresh weight of the pulp. The observations on the loss in weight during storage showed that the percentage loss in weight of fruit ripened at room temperature was not more than five. The differences obtained in the values for percentage of nitrogen in green and ripe fruit could, therefore, be considered significant.

The total nitrogen content showed a wide range, varying from 0·052 per cent in green Fazri Zafrani fruit to 0·152 per cent in green Peter fruit. The percentage of total nitrogen in the fruit of the varieties showing poor keeping quality, like Fazri white or Sali Banda, was nearly equal to the percentage of total nitrogen in the fruit of Alphonso variety which was found to be a good keeper in cold storage. Again, the value obtained for the fruit of Cawasjee Patel variety was low, though the ' storage life ' of the fruit was found to be at least equal to that of the Alphonso fruit. There was, therefore, no indication of a relation of the total nitrogen content to the keeping quality of the fruit.

There was an appreciable difference between the percentages of total nitrogeen in the green and ripe fruit of some of the varieties. In the case of the fruit of the varieties Alphonso (from different localities) Banganpalli and Fazri White, there was a definite increase in the percentage of total nitrogen on ripening. In the case of the fruit of the varieties like Peter, Pyree and Black Andrews, on the other hand, there was a definite decrease in the percentage of total of nitrogen on ripening. As the values represent the total nitrogen content of the pulp only, it appears likely that the difference in the total nitrogen content in the green and ripe fruit may be due to some kind of 'internal movement' of nitrogenous material from the skin and stone to the pulp and vice versa during the process of ripening.

Acidity. The nature of the acids present in mango fruit has not yet been fully investigated. The acidity is, therefore, expressed in terms of malic acid. The percentage of acidity in the green fruit of the different varieties showed a wide variation. The green fruit of Langra variety contained the lowest percentage of acid, 0·67 per cent, and the fruit of Shendrya variety the highest, 3·66 per cent. The values obtained for the percentage of acidity in the green fruit of some of the varieties have been plotted against the 'storage life' (calculated on the ten per cent wastage basis) of the fruit at 45°F. It will be seen from Fig. 5 that there is a correlation between

the acid content of green fruit and the length of the 'storage life', the latter being short in the case of fruit with low acidity and long in the case of fruit with high acidity.

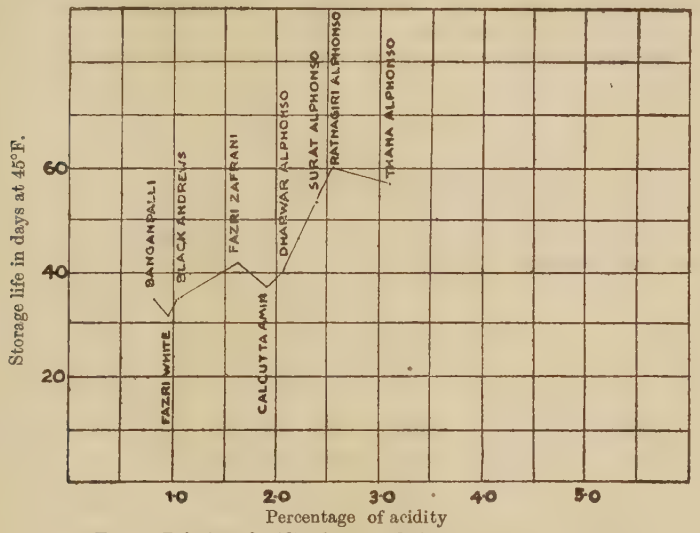


Fig. 5. Relation of acidity in green fruit to storage life at 45°F.

The percentage of acidity decreased in all cases during ripening and the acidity of ripe fruit was in all cases less than 0·60 per cent, being the lowest in the Ratnagiri Alphonso and the Cawasjee Patel fruit (0·18 per cent) and the highest in the Fazri Zafrani fruit (0·56 per cent).

Sugars. The percentage of total sugars in green fruit showed a wide range varying from 1·45 in the green Shendrya fruit to 9·45 in the Kolanka Goa fruit. The percentage of total sugars in green fruit appeared roughly to vary inversely with the percentage of acidity.

The total sugar content increased in all cases on ripening. There was, however no definite relation between the total sugar content in green and in ripe fruit. The percentage of total sugars in ripe fruit also showed a wide variation, ranging from 11·2 in the Cawasjee Patel fruit to 16·8 in the Hemsagar fruit. The content of sugars in ripe fruit did not show any relation to the length of the 'storage life'. The percentage of total sugars in ripe fruit appeared roughly inversely proportional to the percentage of water.

Chemical changes in fruit during storage

For the study of the chemical changes taking place in the fruit stored at different temperatures, the fruit of 'B' stage of maturity of Alphonso variety was obtained from Achhar near Karabele in the Thana District. The fruit was stored in trays

at different temperatures ranging from 30°F. to 68°F. and at room temperature (80°F.-96°F.). The samples were taken at regular intervals during storage and the analyses were carried out for the contents of water, acidity, total sugars—reducing and non-reducing—and total nitrogen. The methods described in the preceding part of this paper were followed both for the sampling and for the chemical analyses. The results of the analyses are given in Tables XLVI—XLIX.

TABLE XLVI

Percentage of water

Number of days of storage	Room temperature (80°F.-96°F.)	Temperature of storage						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
0	81·8	..	..	..	..	..	..	..
4	81·6	80·5	81·4	80·4	81·0	81·8	81·1	80·9
14	83·8	81·7	80·9	80·7	79·5	81·5	81·1	80·2
21	86·1	82·5	81·4	80·1	82·0	81·5	81·3	80·9
28	87·0	83·8	82·0	80·5	81·5	81·4	81·7	80·8
39	88·7	85·2	84·7	80·2	81·7	82·2	81·7	79·8

TABLE LXVII

Percentage of acidity in terms of malic acid on fresh-weight basis

Number of days of storage	Room temperature (80°F.-96°F.)	Temperature of storage						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
0	2·158	..	..	..	..	..	..	..
4	0·514	0·418	0·808	1·218	1·796	2·158	2·182	2·621
14	0·187	0·156	0·265	1·358	1·502	1·156	1·630	1·982
21	0·220	0·152	0·159	1·045	1·747	1·736	1·879	2·031
28	0·200	0·140	0·164	0·714	1·454	1·718	1·852	1·874
39	0·205	0·136	0·147	0·545	0·380	1·678	1·673	2·073

TABLE XLVIII

Percentage of total nitrogen on fresh-weight basis

Number of days of storage	Room temperature (80°F.-96°F.)	Temperature of storage						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
0	0·105	..	..	..	..	..	..	..
4	0·117	0·107	0·109	0·117	0·104	0·105	0·111	0·117
14	0·117	0·108	0·109	0·118	0·112	0·105	0·097	0·103
21	0·128	0·104	0·114	0·102	0·106	0·104	0·104	0·108
28	0·124	0·106	0·101	0·106	0·107	0·108	0·113	0·106
39	0·111	0·113	0·133	0·106	0·113	0·107	0·117	0·121

TABLE XLIX

Percentage of total, reducing and non-reducing sugars on fresh-weight basis

Number of days of storage		Room temperature (80°F.-96°F.)	Temperature of storage						
			68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
4	Total	10·21	12·46	10·45	9·78	8·34	4·98	5·02	5·60
	Reducing	2·74	2·54	3·45	3·82	3·19	2·52	2·56	2·50
	Non-reducing	7·47	9·92	7·00	5·96	5·15	2·46	2·46	3·10
14	Total	10·86	13·85	13·69	11·98	11·40	10·87	9·11	7·25
	Reducing	1·82	1·79	2·66	3·88	4·03	4·36	4·20	3·05
	Non-reducing	9·04	12·06	11·03	8·10	7·37	6·51	4·91	4·20
21	Total	5·05	11·32	12·92	13·94	10·55	10·49	7·15	8·13
	Reducing	2·03	1·60	2·02	3·49	3·98	4·65	3·56	3·53
	Non-reducing	3·02	9·72	10·90	10·40	6·57	5·84	3·59	4·60
28	Total	6·73	8·34	11·19	12·76	12·33	9·31	9·47	7·83
	Reducing	2·09	1·69	1·86	3·20	3·98	3·94	3·79	3·79
	Non-reducing	4·64	6·65	9·33	9·56	8·35	5·37	5·68	4·04
39	Total	7·20	10·30	10·79	13·35	12·25	10·14	7·91	5·73
	Reducing	2·62	2·01	1·84	3·16	4·01	3·97	3·67	3·03
	Non-reducing	4·58	8·29	8·95	10·19	8·24	6·17	4·24	2·70

Water. While the percentage of water practically remained unaffected at 52°F. and the lower temperatures, it showed an appreciable increase during storage at the higher temperatures. The fruit ripened at 60°F., 68°F. and room temperature, and then turned over-ripe, the period required for this change depending on the temperature. The sugars are gradually used up by the fruit for respiration and this change is indicated by the low amount of sugars present in the over ripe fruit which gave higher values for the water content.

Acidity. The percentage of acidity at 68°F. was throughout lower than that at room temperature. The acidity at 60°F. was roughly equal to that at 68°F. after twenty-one days of storage. At 52°F. the value for acidity showed a little increase and then a gradual loss. At 45°F., 40°F. and 35°F., the acidity slightly decreased in the second week of storage, then registered an increase and later a gradual fall as the storage period advanced. At 30° F. there was a rise followed by a drop in the beginning but later the value did not much alter.

The values obtained for the percentage of total nitrogen showed changes which could not easily be correlated. From the chemical composition of fruit of the different varieties of mango given earlier, it will be seen that the total nitrogen content showed an appreciable rise in the case of the Alphonso fruit after ripening. While the fruit at room temperature showed some increase, that at 68°F. and 60°F. did not indicate any definite change, even though it ripened properly at these temperatures.

It appears from the values obtained for sugars that the amount of reducing sugars present was steady and rarely exceeded four per cent. The significant changes were found in the amount of non-reducing sugars.

The amount of total sugars in fruit that ripened at 68°F. and 60°F. was higher than that in fruit ripened at room temperature which agreed with the lower values obtained for acidity at the former temperatures. The over-ripe stage of the fruit at room temperature and 68°F. was marked by the decrease in the amount of total sugars. The increase in the values of total sugars noticed after the drop appeared to be due to the loss in weight as the percentage of total sugars has been calculated on the fresh-weight basis.

The green fruit remained unchanged in outward appearance for four weeks at 52°F. and for nine weeks at 45°F. and the fruit was chilled at 40°F. and the lower temperatures. Even then significant changes in the amount of total sugars were observed in the fruit stored at these temperatures. The percentage of total sugars increased and the fruit tasted sweet although it appeared unripe.

Loss in weight during storage

The loss in weight of the fruit in storage is due to the combined effects of the evaporation of water present in the fruit and the oxidation of organic substances which takes place in respiration. The extent of the loss in weight, therefore, depends on the rate of the evaporation of water and the rate of respiration. The rates of both the processes are slowed down as the temperature is lowered.

In order to follow the loss in weight during storage at the different temperatures twelve fruits of uniform size were selected. They were individually weighed and kept in a tray in each chamber. The fruits were weighed individually at intervals. The results obtained in the case of the fruit of Alphonso, Peter and Suwarnarekha varieties are shown in Tables L, LI and LII respectively. The values for 68°F. have been shown graphically in Fig. 6.

TABLE L.

Loss in weight during storage of the Alphonso fruit

Number of days of storage	Room temperature (80°F.-96°F.)	Percentage loss in weight						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
5	5·2	2·6	1·4	1·2	1·0	0·8	0·7	0·6
13	11·8	6·7	3·8	3·0	2·6	2·1	1·9	1·9
24	18·9	12·0	7·4	6·5	5·2	4·2	4·0	4·6
31	23·6	15·5	9·3	8·5	6·4	5·3	4·9	5·9
42	..	19·7	11·0	11·2	8·4	6·7	6·3	7·4
54	..	..	12·3	13·6	10·5	8·2	8·0	9·0

TABLE LI

Loss in weight during storage of the Peter fruit

Number of days of storage	Room temperature (80°F.-96°F.)	Percentage loss in weight						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
2	3·7	1·7	1·5	1·2	0·9	0·9	1·1	1·1
5	8·1	3·4	2·9	2·1	1·7	1·6	1·7	1·8
8	12·2	5·5	4·4	2·9	2·3	2·1	2·4	2·6
13	20·3	8·3	6·2	4·2	4·3	2·9	3·1	3·8
21	..	11·2	10·0	6·6	5·1	4·7	4·9	5·1

TABLE LII

Loss in weight during storage of the Suwarnarekha fruit

Number of days of storage	Room temperature (80°F.-96°F.)	Percentage loss in weight						
		68°F.	60°F.	52°F.	45°F.	40°F.	35°F.	30°F.
25	7·6	2·5	1·5	1·5	1·3	1·3	1·0	0·8
11	15·2	5·8	3·2	3·1	2·6	2·5	1·9	1·4
18	20·3	9·4	5·0	4·6	3·8	3·8	2·8	2·2
23	..	..	7·4	6·4	4·8	4·6	3·5	3·5
38	..	..	..	10·9	7·5	7·4	5·5	4·5
44	..	..	..	..	8·9	8·7	6·5	5·4

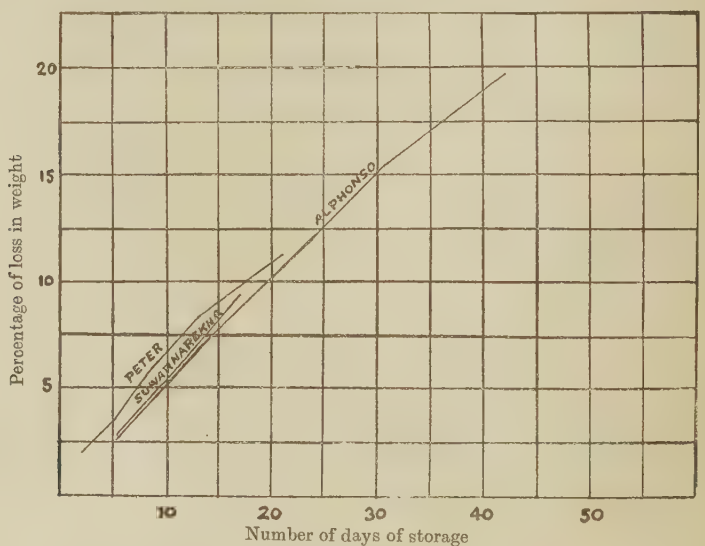


FIG. 6. Loss in weight during storage at 68°F. of Alphonso, Peter and Suwarnarekha fruit

It will be seen from Fig. 6 that the loss in weight increased steadily with the progress of the storage period and that there was no sudden change in the rate of loss at the time when the fruit ripened. The rate of loss in the Peter fruit was more than in the fruit of the other two varieties. This may be due to the high content of total sugars in the green fruit and somewhat rough surface of the skin. The rates of loss

in weight in the Alphonso and Suwarnarekha fruit were generally equal. But the high value obtained for the loss in weight in the Suwarnarekha fruit at room temperature may be due to the high value of water content in the green fruit of this variety. The rate of respiration of the Alphonso fruit was found to be greater than that of the Suwarnarekha fruit [*cold Storage Research Scheme Report*, 1934] and as a result the loss in weight should be expected to be higher in the case of the Alphonso fruit, but this appears to have been counterbalanced by the very smooth skin of the Suwarnarekha fruit which possibly reduced the evaporation of water. In the case of the Alphonso and Peter fruit there was a greater loss at 30°F. than at 35°F. and 40°F., due to the considerable oozing at the former temperature.

Summary

The results of the investigations carried out during the last three seasons on the problem of the cold storage of mango have been described. The work was done at the Cold Storage Research Scheme Laboratories set up in 1934 at the Ganeshkhind Fruit Experiment Station, Kirkee, by the Imperial (now Indian) Council of Agricultural Research, India.

The fruit of 'A' stage of maturity (green but just mature) and of 'D' stage of maturity (ripe on the tree) have been found unsuitable for storage. The fruit of 'B' and 'C' stages of maturity (green and mature, and green and fully mature) was mainly used in these investigations.

Twenty-eight different commercial varieties of mango from the Madras Presidency, United Provinces, Bihar and the Bombay Presidency were tried in cold storage. The Alphonso variety from Bombay is found to be the best keeper. The fruit of the varieties, Peter, Fazri Zafrani, Pyree and Cawasjee Patel could also be kept in good condition for varying periods. The 'B' stage of maturity has been found suitable for cold storage.

Ripe yellow fruit (eating maturity) of all the varieties, with the exception of two varieties, turned brown in cold storage, due to chilling, at all the temperatures from 30°F. to 52°F. Green fruit of 'B' stage of maturity was chilled at the temperatures below 45°F. Pitting, which was very severe at the low temperatures, was found on the skin of the fruit and the fruit either rotted or did not ripen satisfactorily when it was transferred to 68°F. or to room temperature.

The storage behaviour of the fruit of Alphonso variety obtained from five localities in the Bombay Presidency known for the cultivation of this fruit was investigated. The results showed that the Alphonso mango grown at Ratnagiri, Poona, Thana, Surat and Dharwar under different climatic and soil conditions did not show a marked difference in the 'storage life', except in the case of Dharwar fruit which was inferior in keeping quality. The fruit from Ratnagiri remained green at 48°F. and 52°F. for a longer period as compared with the fruit from the other localities.

The rate of ripening of the fruit transferred to 68°F. and to room temperature after cold storage slackened as the period of storage advanced. The chemical analyses of the fruit ripened after cold storage showed that the development of total sugars

was quite normal. The fruit, when ripe, did not turn brown when kept at low temperatures.

Both the big and small fruit behaved similarly in cold storage. It was the stage of maturity that was important in storage and not the size. The rate of loss in weight at 48°F. of the two sizes of fruit was equal.

The fruit having a portion of stalk attached to it after being plucked had no advantage over the fruit without the stalk portion except that the fruit had brighter appearance in the former case. The gum oozing out from the stalk-end caused the development of brown spots on the fruit and it is, therefore, necessary to take care that the fruit is free from the gum.

The fruit was wrapped with white tissue paper, red tissue paper and waxed paper and stored at 48°F. The observations showed that though the fruit appeared sound and unaffected on unwrapping after six weeks of storage, wrapping was found to have impaired the ripening power of the fruit and this was more marked in the case of waxed paper.

The effect of different packing materials was investigated. The results showed that mango and *karanj* leaves and saw-dust were quite unsuitable for packing fruit for cold storage. Rice straw and wood-wool did not affect the fruit while in cold storage, but vitiated the ripening to a certain extent as the fruit rotted rapidly when transferred to 68°F.

A wooden crate of the size of 24 in. × 12 in. × 12 in., capable of holding about a hundred mangoes, was found to be a suitable kind of package for commercial cold storage. As wrapping the fruit individually was found to be harmful and the packing materials, like rice straw and wood-wool, affected the ripening of the fruit to a certain extent after cold storage, wrapping fruit individually and packing it tightly with rice straw or wood-wool should be avoided, using only a light wadding of the packing material to hold the fruit in position and to minimise bruising in handling the packages.

Most of the decay of the fruit was found to be due to a species of *Gloeosporium mangiferae*. The same fungus was responsible for stem-end rot, lateral rot, 'watery rot' and the development of 'brown patches'. The experiments on the effect of different treatments in retarding the development of 'brown patches' in the case of Suwarnarekha and Banganpalli fruit were attended with negative results.

The chemical composition of the green and ripe fruit of different varieties of mango was studied. Determinations were made of the percentages of water, total nitrogen, acid and sugar contents. It has been found that there is a correlation between the acid content of green fruit and the length of the 'storage life', the latter being short in the case of fruit with low acidity and long in the case of fruit with high acidity.

The changes in the chemical composition of Alphonso fruit stored at different temperatures were followed. The fruit ripened at 68°F. or 60°F. contained more total sugars than that ripened at room temperature. The sugars were rapidly consumed

when the fruit became over-ripe. Significant chemical changes were found to occur in the fruit remaining green at the temperatures of 30°F. to 52°F.

There was a steady loss in weight of the fruit in storage. There was no sudden change in the rate at the time of ripening.

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INFLUENCE OF ALGAL GROWTH IN THE RICE FIELDS ON THE YIELD OF CROP*

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IT has been observed in a previous experiment that on the addition of phosphates to water-logged rice soils both algal growth as well as the fixation of nitrogen by them are considerably stimulated [1941]. This observation suggests a possibility of enhancing the fertility of rice soils by means of algal growth an abundance of which will enrich the soils not only with nitrogen fixed by them, but also with the organic matter derived from their dead bodies. The question now arises whether an abundant growth of algae in rice-fields is desirable in view of the fact that such a growth, while enriching the soil, may at the same time do considerable harm to growing crop by competing with the latter for supply of available nutrients. The primary object of agriculture is to grow crop. Any process, therefore, which impedes crop growth must be avoided at all costs however beneficial it may be from other points of view. It is important, therefore, that a knowledge of the effect of algae on the growth of crop must be obtained before algal growth can be recommended as a means of enhancing soil fertility.

Accordingly a 5-year course pot culture experiment was undertaken with the object of finding out how the growth of rice crop, as determined by the yields of grain and straw, is affected by an abundant growth of algae in soils. The details of the experiment are as follows :

The experimental unit was a wide mouth glass bottle containing 5 lb. of soil and fitted with a cork having a circular bore (one inch diameter) at the centre. For each soil, 20 such bottles were used which were treated as follows :

Bottle number	Treatment
(1) 1—5	Soils waterlogged by distilled water and exposed to sunlight.
(2) 6—10	Same as (1), but received in addition 1500 c.c. of a nitrogen-free nutrient solution‡ added in several instalments throughout the experiment.
(3) 11—15	Same as (1), but the soils were kept in the dark.
(4) 16—20	Same as (2) but the soils were kept in the dark.

* The work described in this paper was done before the senior author left the Dacca University in September 1947.

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‡ K_2HPO_4—·5gm., $MgSO_4$, $7H_20$—·2gm. Ca_3PO_4—1·0 gm. $CaSO_4$—·1 gm. $FePO_4$ ·1gm. Water—1000 c.c.

Bottles in the dark were first painted outside by Japan black and afterwards wrapped upto the neck with black paper, while those in the light were wrapped with black paper only upto the height of the soil, so as to expose the soil surface and the supernatant water above to sun, thus obtaining conditions approximating those in the field. Each bottle was transplanted with two rice seedlings passing through the hole in the cork and held in position by loose cotton plugging. The whole set of bottles was thereupon placed at random positions in the pot culture house and exposed to sun.

Two soils, Tippera and Faridpur, were used in this experiment. The growth of algae was very rapid in all bottes in the light with continuous evolution of innumerable tiny bubbles of gases during the day time. The growth at first appeared on the surface of the soil, extending therefrom to the side of the bottle and ultimately forming a thin continuous sheet on the top of water. With both soils, the growth was much more luxuriant in the presence of solution than in the controls (soil+water); the ultimate bulk of growth, however, was much heavier in Tippera than in the Faridpur soil. There was no visible growth of algae in the bottle kept in the dark, and the temperature difference between the two sets of cultures (light and dark) were negligible. At the conclusion of the experiment, the plants were cut just above the soil surface by means of a bent scissor. Straw and grains were separated, dried and then weighed. The data for yields of grains and straw per pot in different years with the statistical interpretation are given in the appendix.

The experiment was continued for five years [1940-1944]. After each year's experiment, the pots were left undisturbed and were again used for the following years' exepriments each bottle receiving exactly the same treatments as it received in the previous year. Tables I and II show respectively the average yeild of grains and straw in different years.

TABLE I

Average yields of grains in different years

(Weight in grams in each treatment)

Treatments		1940	1941	1942	1943	1944
Faridpur soil						
Soil+water	Light	2.06	1.98	1.95	2.47	2.67
	Dark	2.52	2.49	1.87	1.76	1.46
Soil—solution	Light	2.93	3.26	3.60	4.09	4.82
	Dark	2.92	2.88	2.09	2.00	1.72
Tippera soil						
Soil+water	Light	5.12	3.68	3.87	4.68	5.31
	Dark	5.26	4.35	3.80	3.52	3.00
Soi +solution	Light	5.90	5.38	7.57	8.46	9.43
	Dark	5.88	5.73	4.07	3.83	3.54

TABLE II

Average yields of straw in different years

(Weight in grams in each treatment)

Treatments		1940	1941	1942	1943	1944
Faridpur soil						
Soil+water	Light	3.68	5.58	4.69	5.00	5.68
	Dark	4.67	5.27	4.82	4.42	3.81
Soil+solution	Light	5.27	8.41	8.75	8.95	9.80
	Dark	5.82	7.35	4.92	4.37	4.05
Tippera soil						
Soil+water	Light	10.07	9.03	8.21	8.44	10.13
	Dark	11.41	9.56	8.45	6.40	5.85
Soil+solution	Light	11.55	12.37	13.70	13.78	1566
	Dark	11.52	11.68	8.47	7.17	6.60

It will be seen that in the untreated soils the yields of both straw and grain in the light (algae present) were not very much different from those in the dark (algae absent) in the first three years. Thereafter there was a progressive decrease in yield in the dark and a similar increase in the light, so that on the fourth and fifth years the latter was distinctly higher than the former.

These differences between the two treatments are very clearly seen in soil plus solution cultures. Here again there was not much difference between the yields in the light and in the dark in the first two years, but thereafter there was a gradual increase in the former and a marked fall of the latter. Thus in the fifth year the yields in the light were not only much greater than those at start but also were in all cases at least 100 per cent higher than the corresponding yields in the dark. It is also to be observed that the yields in the dark in the fifth year are much less than those at start. These observations thus show that as a result of continuous cultivation the soils have gradually become deficient in nitrogenous plant food, and that algal growth has not only made up this deficiency, but has also made the soil even richer than what it was in the beginning of the experiment. A comparison of the yields of the crop in the control with that in the corresponding treated pots (both in the dark) show that there is not much difference between them at start. The solution added thus appears to have little fertilizing effect on the growth of the crop, although it has considerable effect on the growth of algae. The much higher yields in the treated pot in the light as compared with that in the corresponding control must therefore be attributed to more abundant algal growth in the former.

At the end of 5th year's experiment, three pots from each treatment were selected at random and the soil contained therein was taken out, powdered, passed through 1 mm. seive and then analyzed for total nitrogen. The results are given in Table III.

Table III

Changes in total nitrogen contents of soils. (*N as p.p.m.*)

(Averages are in parentheses)

Treatment		N at start (1940)	N after the experiment (1945)	Gain or loss	Remarks
Faridpur soil					
Soil+water	Light	650	673	+23	Moderate
		650	700	+50 (+30)	algal growth
		650	667	+17	
	Dark	650	580	—70	No algal
		650	566	—84 (—75)	growth
		650	580	—70	
Soil+solution	Light	650	826	+176	Luxuriant algal growth
		650	833	+185	
		650	846	+196	
	Dark	650	606	—44	No algal growth
		650	610	—40 (—45)	
		650	600	—50	
Tippera soil					
Soil+water	Light	1140	1190	+50	Moderate algal growth
		1140	1180	+40 (+40)	
		1140	1170	+30	
	Dark	1140	1006	—134	No algal growth
		1140	1030	—110 (—125)	
		1140	1010	—130	
Soil+solution	Light	1140	1400	+260	Luxuriant algal growth
		1140	1330	+190 (+220)	
		1140	1350	+210	
	Dark	1140	1060	—80	No algal growth
		1140	1070	—70 (—80)	
		1140	1050	—90	

The results show that the pots, in which an abundant algal growth had taken place, gained considerably in nitrogen, while there was a loss of this element from all the pots kept in the dark. Algal growth thus has not only increased the yield of the rice crops, but has also improved the nitrogen status of t' e soils.

Summary

A 5-year course Pot Culture Experiment was performed to find out the effect of algal growth in soils on the yield of rice crop. In this experiment rice plants were grown in pots in some of which soils were kept in the dark (algae absent), while in others the soil surface and the supernatant water above were exposed to light (algae present).

The results show that during the first two or three years, the yields of the crop in presence and in absence of algae were not very much different, but thereafter there was a progressive increase of the former and a similar fall of the latter so that in the fourth and fifth year the yields in presence of algae were not only much higher than those in their absence, but also than those at start.

Determination of nitrogen at the end of the experiment has shown considerable increase in nitrogen in soils in which algae grew abundantly. On the other hand, soils in which algal growth was absent, showed loss of this element.

Acknowledgments

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REFERENCE

De, P. K. and Sualiman, M. (1941). *Report of the work done under the Dacca University Scheme of Research on the Nutrition of Rice Plants with special reference to Nitrogen Supply, 1941-42.*

Appendix

Potculture Experiment with aman *Paddy, 1940*

Yields in gram of straw and grain per culture vessel

(Averages in parentheses)

Treatment		Bottle number	Straw	Grain
Faridpur soil				
Soil+water	Light	1	3·11	2·08
		2	..	..
		3	4·23 (3·68)	2·05 (2·06)
		4	3·41	1·81
		5	3·97	2·30
	Dark	6	4·96	2·69
		7	3·87	2·33
		8	6·33 (4·67)	2·59 (2·52)
		9	4·06	2·07
		10	4·11	2·90
Soil+solution	Light	11	4·88	2·49
		12	5·86	2·94
		13	5·97 (5.27)	2·94 (2·93)
		14	4·55	2·60
		15	5·11	2·68
	Dark	16	5·12	2·26
		17	6·35	3·15
		18	5·72 (5·82)	2·90 (2·92)
		19	5·81	3·06
		20	6·10	3·21

APPENDIX—*contd.*

Potculture Experiment with aman *Paddy, 1940*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages in parentheses)

Treatment		Bottle number	Straw	Grain
Tippera soil				
Soil + water	Light	21	9·38	4·95
		22	9·78	5·00
		23	10·36 (10·07)	5·24 (5·12)
		24	10·12	4·98
		25	10·70	5·44
	Dark	26	11·12	6·57
		27	10·46	5·26
		28	12·10 (11·41)	5·58 (5·26)
		29	11·95	4·36
		30	11·42	4·53
Soil + solution	Light	31	11·15	4·04
		32	11·56	5·91
		33	12·25 (11·55)	6·81 (5·90)
		34	11·31	6·42
		35	11·48	6·34
	Dark	36	13·20	4·20
		37	10·67	6·86
		38	11·86 (11·51)	5·98 (5·88)
		39	11·06	6·63
		40	10·73	5·74

APPENDIX—*contd.*

Poiculture Experiment with aman *Paddy, 1941*

Yields in gram of straw and grain per culture vessel

(Averages in parentheses)

Treatment		Bottle number	Straw	Grain
Faridpur soil				
Soil+water	Light	1	5·59	1·97
		2	4·90	1·14
		3	6·12 (5·38)	1·97 (1·98)
		4	5·44	2·15
		5	5·87	2·64
	Dark	6	5·08	2·49
		7	4·92	2·18
		8	4·65 (5·27)	2·56 (2·49)
		9	6·47	2·72
		10	5·22	2·50
Soil+solution	Light	11	7·90	3·38
		12	7·56	4·22
		13	9·20 (8·41)	2·37 (3·26)
		14	7·71	3·28
		15	9·67	3·03
	Dark	16	6·16	3·09
		17	7·37	2·86
		18	7·35 7·35	2·87 (2·88)
		19	7·02	2·74
		20	8·87	2·84

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1941*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages in parentheses)

Treatment		Bottle number	Straw	Grain
Tippera soil				
Soil+water	Light	21	8·85	3·37
		22	8·05	3·91
		23	9·21 (9·03)	3·79 (3·68)
		24	8·68	3·17
		25	10·37	4·19
	Dark	26	9·00	3·65
		27	8·77	4·71
		28	9·48 (9·56)	4·00 (4 35)
		29	9·70	4·67
		30	10·84	4·71
Soil+solution	Light	31	10·08	5·90
		32	9·96	7·08
		33	15·57 (12·37)	6·39 (6·38)
		34	11·75	6·15
		35	14·48	6·38
	Dark	36	10·25	6·92
		37	11·84	5·57
		38	14·30 (11·68)	4·35 (5·73)
		39	9·20	5·48
		40	12·65	6·32

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1942*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Faridpur soil				
Soil+water	Light	1	4·25	1·96
		2	4·45	2·06
		3	4·85 (4·69)	1·74 (1·95)
		4	4·60	1·98
		5	5·30	2·01
	Dark	6	4·86	1·85
		7	4·55	1·84
		8	4·96 (4·82)	1·67 (1·87)
		9	5·10	1·93
		10	4·62	2·06
Soil+solution	Light	11	8·30	3·53
		12	9·25	3·45
		13	8·50 (8·75)	3·69 (3·60)
		14	8·05	3·14
		15	9·55	4·18
	Dark	16	4·72	2·07
		17	5·05	1·86
		18	5·45 (4·92)	2·08 (2·09)
		19	4·20	2·17
		20	5·16	2·28

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1942*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Tippera soil				
Soil+water	Light	21	7·76	3·90
		22	7·55	3·78
		23	9·00 (8·21)	3·85 (3·87)
		24	8·45	3·88
		25	8·30	3·97
	Dark	26	8·10	3·72
		27	8·65	3·94
		28	9·20 (8·45)	3·70 (3·80)
		29	7·90	3·86
		30	8·40	3·78
Soil+solution	Light	31	12·85	7·27
		32	15·00	7·84
		33	14·30(13·70)	7·85 (7·57)
		34	12·70	7·07
		35	13·82	7·80
	Dark	36	9·65	4·35
		37	8·05	3·69
		38	7·70 (8·47)	4·25 (4·07)
		39	8·75	4·31
		40	8·20	3·75

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1943*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Faridpur soil				
Soil+water	Light	1	4·62	2·39
		2	5·60	2·31
		3	4·74 (5·00)	2·59 (2·47)
		4	5·20	2·60
		5	4·85	2·46
	Dark	6	4·83	1·91
		7	4·05	1·67
		8	4·48 (4·42)	1·77 (1·76)
		9	4·26	1·60
		10	4·50	1·85
Soil+solution	Light	11	8·15	3·65..
		12	8·50	4·28
		13	9·34 (8·96)	4·64 (4·09)
		14	9·55	3·92
		15	9·25	3·95
	Dark	16	4·02	1·99
		17	4·38	2·12
		18	5·10 (4·37)	2·30 (2·00)
		19	4·20	1·85
		20	4·14	1·74

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1943*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Tippera soil				
Soil+water	Light	21	8·75	4·84
		22	9·00	4·42
		23	8·08 (8·44)	4·83 (4·68)
		24	7·72	4·40
		25	8·65	4·93
	Dark	26	6·60	3·35
		27	7·15	3·55
		28	6·02 (6·40)	3·37 (3·52)
		29	6·05	3·64
		30	6·20	3·67
Soil+solution	Light	31	13·27	8·56
		32	14·06	8·10
		33	14·11 (13·78)	9·01 (8·46)
		34	13·90	8·70
		35	13·66	7·93
	Dark	36	7·06	4·06
		37	6·62	3·61
		38	6·55 (6·77)	3·65 (3·83)
		39	8·05	4·20
		40	7·58	3·61

APPENDIX—*contd.*

Potculture experiment with aman *paddy, 1944*—contd.

Yields in gram of straw and grain per culture vessel—contd.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Faridpur soil				
Soil + water	Light	1	5·30	2·50
		2	5·80	2·78
		3	4·96 (5·68)	2·28 (2·67)
		4	6·53	2·87
		5	5·80	2·92
	Dark	6	3·60	1·43
		7	3·60	1·35
		8	3·86 (3·81)	1·41 (1·46)
		9	4·21	1·80
		10	3·80	1·33
Soil + solution	Light	11	9·56	4·98
		12	8·60	4·34
		13	9·80 (9·80)	4·50 (4·82)
		14	9·85	4·67
		15	11·20	5·61
	Dark	16	3·50	1·63
		17	4·65	2·16
		18	3·75 (4·05)	1·57 (1·72)
		19	4·31	1·71
		20	4·04	1·53

APPENDIX—*concld.*

Potculture experiment with aman *paddy, 1944*—concld.

Yields in gram of straw and grain per culture vessel—concld.

(Averages are in parentheses)

Treatment		Bottle number	Straw	Grain
Tippera soil				
Soil+water	Light	21	9·25	4·42
		22	10·80	5·45
		23	9·45 (10·13)	4·88 (5·31)
		24	10·50	5·83
		25	10·65	5·95
	Dark	26	6·00	2·60
		27	5·40	3·31
		28	5·82 (5·85)	3·22 (3·00)
		29	6·71	2·75
		30	6·31	3·14
Soil+solution	Light	31	16·10	9·22
		32	15·52	9·08
		33	15·56 (15·66)	9·03 (9·43)
		34	16·25	10·00
		35	14·87	9·82
	Dark	36	6·10	3·72
		37	5·85	2·99
		38	7·65 (6·60)	3·75 (3·54)
		39	7·00	3·56
		40	6·71	3·70

Analysis of variance

(Averages are in parentheses)

Sources of variations	D.F.	S. Squares	Variance	Ratio
Year	4	1·0363	·2591	..
Treatment	1	18·6049	18·6049	59·919**
Algae	1	16·3073	16·3073	52·519**
Locality	1	67·1846	67·1846	216·365**
Interactions	..	..	..	..
Year × treatment	4	1·3557	·3389	1·091
Year × algae	4	15·8503	3·9626	12·762**
Year × locality	4	·3723	·0931	..
Treatment × algae	1	8·1180	8·1180	26·145**
Treatment × locality	1	2·0794	2·0794	6·697*
Algae × locality	1	2·1623	2·1623	6·964*
Error	17	5·2769	·3105	..
Total	39	138·3470	..	..

* Indicates significant at 5 per cent level
** Indicates significant at 1 per cent level

The yields of paddy have been undoubtedly different for different treatments as well as for the different localities. Algae have also produced appreciable difference in the yields. But in all the years the yields appear to be substantially the same.

The variations of yield due to treatment have been greatly influenced by the presence or absence of algae. In other words, the effect of treatment in the presence of algae has been different from that in the absence of algae.

Though differences in year have shown no effect on the whole, it appears that contrasts between the various yearly yields are different according as algae is present or absent.

The effect due to both treatment and algae appears to be somewhat dependent on the locality, though such dependence is of doubtful significance.

OXIDATION OF MANGANESE COMPOUNDS IN SOILS

EFFECT OF EXCHANGEABLE BASES AND *p*H

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(With Plates XVI—XIX)

THERE is ample evidence to indicate that the predominant role of oxidation in the soil is played by micro-organisms. Beijerinck [1913] has described several fungi and bacteria which are capable of oxidising manganese carbonates to oxides. The transformation of manganese salts into manganic hydroxide usually takes place in the alkaline media. The possibility of micro-biological precipitation has also been demonstrated by Sohngen [1914]. Gerretsen [1935, 1937] has expressed the opinion that the precipitation of insoluble manganic oxides in the soil by micro-organisms takes place between *p*H 6·5 and 7·8.

Recently Leeper and Swaby [1940] has carried out a number of experiments on the oxidation of manganese in the soil. Their conclusions are that the microbiological oxidation takes place on plaques of which the final *p*H ranges from 4·8 to 8·9.

The object of the present investigation was to study the phenomenon of oxidation of manganese compounds in soils and the effect of the major exchangeable bases at varying *p*H values on the oxidation of manganese compounds in soil.

Experimental

The soil used for the above investigation was a medium loam containing about 16 per cent clay, and converted into sodium, potassium, calcium and magnesium soils of different *p*H values [Hoon and Dhawan, 1940]. Plaque method as described by Leeper and Swaby [1940] was followed.

Five grams of the soil was shaken with 10 c.c. of sterlized distilled water and was further mixed with 10 c.c. of 2·0 per cent agar which was poured in petri dishes. After the solidification of the agar, a hole of about $\frac{1}{2}$ inch in diameter was punctured in the centre of the petri dishes. One cubic centimetre of 1·0 per cent manganese salt solution in agar was poured in the centre of the holes. Plates were kept at 30°C. in the autoclave and observations taken daily.

The Table I shows the type of soil and the allied *p*H.

TABLE I

Type of soil allied p*H*

Serial number	Type of soil	*p*H
1	Hydrogen soil	5·6
2	Sodium soil	7·8
3	do.	8·6
4	do.	9·7
5	do.	10·5
6	Potassium soil	7·5
7	do.	8·8
8	do.	9·4
9	do.	9·8
10	Calcium soil	7·6
11	do.	8·4
12	do.	9·0
13	do.	9·4
14	Magnesium soil	7·4
15	do.	8·1
16	do.	8·4
17	do.	8·75

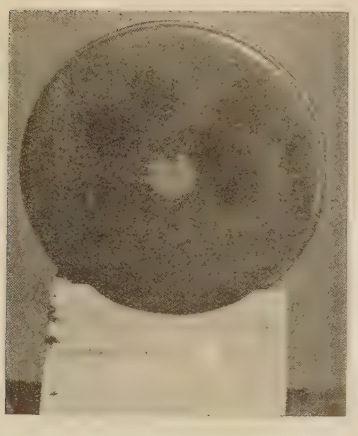
DISCUSSION OF RESULTS

The samples studied in the present investigation show a remarkable variation in behaviour. Each soil has given a characteristic pattern depending upon the dominant base and the *p*H of the soil. Some of them have developed a ring of brown spots, while in some there is a uniform brown zone formation. The brown spots develop most rapidly at lower *p*H values. In some highly alkaline medium we find the appearance of white incrustation, which in fact is the precipitation of manganese carbonate. The following are the main conclusions in each soil.

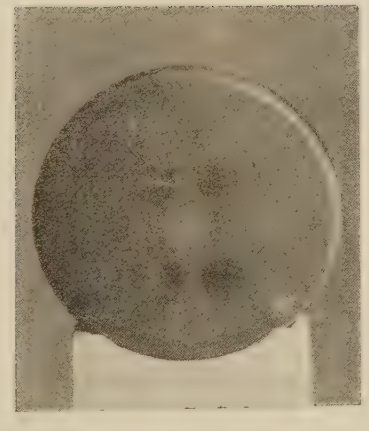
Sodium soil

The first two soils (Plate XVI, plaques No. 1 and 2) having 7·8 and 8·6 *p*H values developed fine rings. The remaining two soils possessing 9·7 and 10·5 *p*H

SODIUM SOILS



Plaque No. 1
p_H=7·8

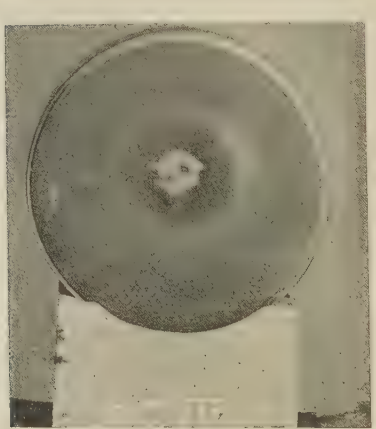


Plaque No. 2
p_H=8·6

POTASSIUM SOILS

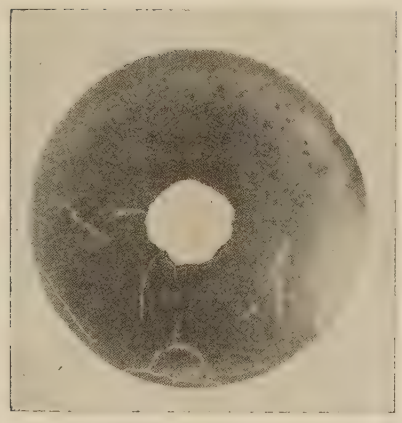
Plaque No. 3
p_H=7·5

Plaque No. 4
p_H=8·8



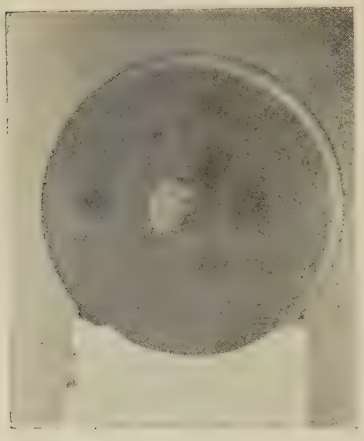
Plaque No. 5
p_H=9·4

CALCIUM SOILS

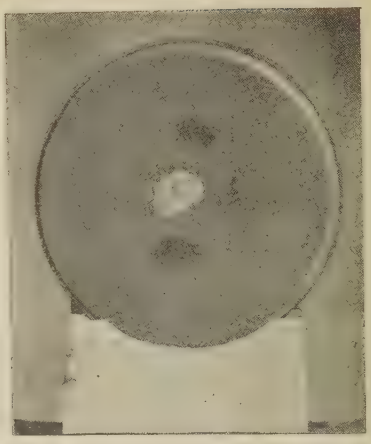


Plaque No. 6
p_H=7·6

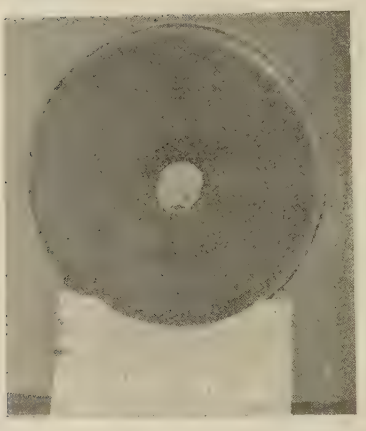
MAGNESIUM AND HYDROGEN SOILS



Plaque No. 7
p_H=7·4

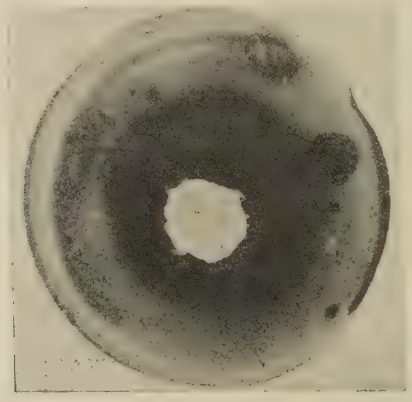


Plaque No.
p_H=8·1



Plaque No. 9
p_H=8·4

Plaque No. 10
p_H=8·75



Plaque No. 11
p_H=5·6

values did not develop any ring or zone formation. The results showed that the oxidation did not take place above a certain *p*H value. At this stage more manganese would be available to the plant which might at times reach the toxic stage.

Potassium soil

Plaques No. 3-5 (Plate XVII) show the effect of potassium soil on the oxidation of manganese in soils. Potassium is also treading the same path as sodium. The diameter of the circular ring is very small as compared with the sodium soil.

Calcium soil

There was a random formation of brown spots in every plaque, which meant that the oxidation had set in all the soils irrespective of *p*H. Plaque No. 6 (Plate XVIII) shows the effect of calcium soil (*p*H 7·6) on the microbiological oxidation of manganese.

Magnesium soil

In plaque No. 7 (Plate XIX) having *p*H 7·4, there were big rings, larger in diameter than in potassium soil. In No. 8 plaque (Plate XIX), *p*H 8·1, there were only two and in the Nos. 9 and 10 *p*H 8·4 and 8·75, the ring formation was noticeable near the centre.

Unsaturated soil

The unsaturated soil (plaque No. 11, Plate XIX) containing no base, had also been examined. There were only two rings near the outer ridge and a few brown spots here and there, which signified that the oxidation was not stopped even in hydrogen soil.

Conclusions

The oxidation proceeds even in acid soils.

The oxidation activity vanishes at *p*H values above 9·0 in sodium and potassium soils.

The effect of *p*H on the oxidation of manganese compounds is very little in the case of calcium soils.

The nature of base and *p*H value effect the oxidation of manganese compounds in soils.

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A STUDY OF PREMATURE DROPS IN ORANGES IN BIHAR

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(With Plate XX)

IT is now almost universally admitted that the original home of citrus is the tropical regions of Southern Asia including China, India and regions between these two countries. Citron has been found to grow wild in India in the Nilgiris, Assam and the lower Himalayas.

Records show that citrus fruits have been under cultivation for over 2,000 years [Hu., 1934].

A world survey of the citrus areas shows that, although this fruit originated in the tropical regions it is flourishing very much in, and the world markets have been captured by the countries, lying in the sub-tropical regions. To day the U. S. A., where citrus was introduced as late as [1493] A.D. [Webber and Batchelor, 1948], is the leading citrus producing country in the world, with 40 per cent (*Govt. Ind. Market. Ser.* 1942-43), of the total world acreage and India one of the homes of origin is the sixth (*Govt. Ind. Market. Ser.* 1942-43), in the list.

In India its cultivation is mostly localised in the various regions. The following table shows the acreage of citrus fruits in various parts of India (*Govt. India Market Ser.* 1942-43).

Table I

Acreage of citrus fruits in various parts of India

Provinces and States	Total acreage	Provinces and States	Total acreage
Assam*	14,025	Kashmir	800
Bengal*	3,335	Mysore	1,330
Bombay	16,400	Baroda	359
C. P.	22,947	Patiala	1,305
Delhi	415	Cochin	270
Orissa	1,200	Travancore	300
Punjab*	17,150	Coorg	10,071
U. P.	1,147	Gwalior	344
Madras	31,270	Hyderabad	2,700

*Pre-partition days

Apart from these there is not a single village in India which may not claim to have one or two citrus trees.

N

The amount of citrus fruits produced in India is not enough to meet the local demands and hence, every year large amounts of citrus fruits have to be imported into India (*Govt. India Market Ser.* 1942-43).

TABLE II

Imports of citrus fruits into India in 1939-40

Country	Maunds	Percentage
Union of South Africa	2,283	66·8
Palestine	510	8·2
Australia	174	5·7
U. S. A.	102	3·3
Egypt	365	3·9
Other countries	616	12·1
Total	4,050	100·0

It is only recently that special attention has been paid to this fruit in our country, more so since the division of the country, when some of the important citrus growing tracts have fallen to Pakistan.

The various avenues for extension of cultivation, improving the yield and studying the various problems facing this industry, with a view to suggesting means of overcoming them, are being studied.

In Bihar a survey of this industry has shown that its cultivation is localised in certain areas, and in recent years the cultivation of oranges is increasing by leaps and bounds, as is illustrated in the following table :—

TABLE III

Total orange acreage in Bihar

Year	Area in acres	Number of localities
1945	879	97
1946	1,028	169
1947	1,261	234
1948	1,487	332

The cultivation of citrus fruits in Bihar is well spread, although the soil types and the climate varies from place to place. Below is given in Table IV the distribution of fruits in Bihar with the average rainfall, humidity and soil characters.

TABLE IV

Distribution of citrus fruits in Bihar with rainfall, humidity and soil character

Regions	Varieties cultivated	Normal rainfall	Humidity	Soil character
1. *North of Ganges*				Rich alluvium, sandy loam to loam with hard clay to yellow clay in the north. Area lying between Kosi and Ganges is flooded. Muzaffarpur soils have calcium upto 20 per cent, others only 2 per cent. Water level is higher in all districts excepting Saran.
Saran	Lemon	46 in.	68	
Champaran	Lime	53 in.	91	
Muzaffarpur	Lime	46 in.	78	
Darbhanga	Lime	49 in.	79	
North Monghyr	Lime and lemon	49 in.	75	
North Bhagalpur	Lemon	51 in.	88	
Purnea	Lime	68 in.	90	
2. *Whole Chhotanagpur and South Bihar portions along the Vindhya Ranges*				600 to 3,000 ft. above sea level. Soil lateritic, hilly and undulating, lacks in humus. Calcium between 3 to 4 per cent.
Ranchi	Limes and oranges	59 in.	60	
Hazaribagh	do.	50 in.	57	
Singhbhum	do.	56 in.	80	
Manbhum	do.	52 in.	78	
Palamau	Oranges, pomello and shaddock	50 in.	82	
Santhal Parganas	Oranges, *maltas* and limes.	55 in.	70	
3. *South Monghyr*	do.	49 in.	75	North-east of Palamau and South-east of Gaya. 600 to 1,500 ft. above sea level has gravelly to Gangatsoil calcium 3 to 4 per cent hilly and undulating.
(Jamalpur to Jamui) Gaya	Limes and oranges	45 in.	68	
4. *Rest of Bihar*				Upto 600 ft. above sea level. Clay to heavy clay with some parts, hilly.
Patna	Lemon	42 in.	75	
Shahabad	Lemon and oranges	43 in.	75	
Rest of Gaya	Lemon	45 in.	75	
Rest of Monghyr	Lemon	49 in.	75	
South Bhagalpur	Lime	51 in.	80	

TABLE V

Premature droppings of fruits in different citrus growing tracts in Bihar and its possible relation to rainfal conditions

Serial number	Date and month	Chianki Farm						Nawadam Farm					
		1945-46		1946-47		1947-48		1945-46		1946-47		1947-48	
		Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop
1	15 to 23 July	..	..	..	..	..	..	..	..	..	..	..	..
2	24 to 31 July	100	..	13·72	..	15·00	..	8·18	..	8·46	..	9·49	..
3	1 to 7 August	..	..	..	..	..	20·6	..	..	..	3·9	..	6·2
4	8 to 14 August	..	..	..	..	..	9·0	..	..	..	1·8	..	8·1
5	15 to 21 August	..	..	..	..	..	9·0	..	..	..	3·7	..	4·9
6	22 to 28 August	6·5	..	21·91	17·4	10·11	7·8	7·30	..	12·68	3·0	9·08	4·5
7	29 August to 4 September	..	..	..	15·3	..	9·9	..	..	..	8·0	..	6·6
9	5 to 11 September.	..	..	..	9·7	..	7·8	..	..	..	11·3	..	8·7
9	12 to 18 September	..	..	..	10·4	..	7·5	..	..	..	14·2	..	7·9
10	19 to 25 September	..	23·9	..	13·4	..	8·0	..	19·5	..	11·7	..	7·8
11	26 September to 1 October	8·56	11·4	14·73	36	3·1	12·96	8·31	18·5	7·86	9·1	6·1	7·1
12	2 to 8 October	..	18·2	..	4·2	..	3·9	..	14·5	..	10·4	..	8·5
13	9 to 15 October	..	14·7	..	8·8	..	4·1	..	10·2	..	7·3	..	7·4
14	16 to 22 October	..	14·7	..	4·2	..	4·1	..	12·2	..	5·6	..	6·5
15	23 to 29 October	5·33	10·4	6·92	3·0	3·09	3·6	4·07	11·5	5·50	3·1	1·17	7·0
16	30 October to 6 November	..	2.3	..	30	..	0·5	..	5·2	..	1·4	..	7·3
17	6 to 12 November	..	0·8	..	1·1	..	*nil*	..	1·8	..	1·6	..	1·3
18	13 to 19 November	..	1·8	..	1·2	..	*nil*	..	2·6	..	2·2	..	*nil*
19	20 to 26 November	..	0·6	..	0·6	..	*nil*	..	1·9	..	0·6	..	*nil*
20	27 November to 3 December	0·6	01	2·24	1·9	..	*nil*	..	1·7	1·10	0·5	..	*nil*
21	4 to 10 December .	..	1·0	..	1·4	..	*nil*	..	0·2	..	..	..	*nil*
22	11 to 17 December	..	..	..	1·0	..	*nil*	..	0·1	..	*nil*	..	*nil*
23	18 to 24 December	..	..	..	1·1	..	*nil*	..	*nil*	..	*nil*	..	*nil*
24	25 December onwards	0·2	0·1	0·33	1·0	0·31	*nil*	0·12	*nil*	..	*nil*	..	*nil*
	Total drop number		6·32		3,715		412		2,421		2,174		1,636
	Total harvest		2,529		4,002		2,812		1,065		8,848		2,661
	Total fruiting		3,161		7,717		3,224		3,486		6,022		4,297
	Percentage of drop		20·0		48·1		12·8		69·4		36·0		40·9

TABLE V—*contd.*

Premature droppings of fruits in different citrus growing tracts in Bihar and its possible relation to rainfall conditions—contd.

Serial number	Date and month	(Jamui) Jamui Farm						(Bikramganj) Bikramgan Farm					
		1945-46		1946-47		1947-48		1945-46		1946-47		1947-48	
		Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage of drop	Rainfall in inches	Percentage in drop	Rainfall of inches	Percentage of drop	Rainfall in inches	Percentage of drop
1	15 to 23 July	..	..	..	..	..	..	..	..	..	..	..	..
2	24 to 31 July	10·12	..	13·14	..	13·26	..	..	..	13·08	..	12·95	..
3	1 to 7 August	..	..	..	9·7	..	..	..	..	..	3·3	..	4·2
4	8 to 14 August	..	..	..	4·1	..	..	..	..	..	8·2	..	6·4
5	15 to 21 August	..	..	..	10·8	..	1·0	..	..	..	3·3	..	9·1
6	22 to 28 August	8·09	..	8·77	1·4	6·84	1·1	..	..	18·56	9·8	8·29	10·6
7	29 August to 4 September	..	..	..	3·5	3·3	3·3	..	..	..	4·9	..	5·1
8	5 to 11 September	..	..	..	11·1	..	12·0	..	..	..	9·8	..	12·3
9	12 to 18 September	..	19·3	..	10·8	2·0	8·6	..	..	..	11·5	..	9·4
10	19 to 25 September	..	10·0	..	9·7	..	8·4	..	..	..	6·5	..	8·0
11	26 Septemberto 1 October	9·1	12·2	5·71	9·0	8·92	10·1	..	..	11·50	1·6	7·03	8·5
12	2 to 8 October	..	7·1	..	10·8	..	21·6	..	..	..	9·8	..	3·3
13	9 to 15 October	..	11·5	..	9·7	..	15·5	..	..	..	8·9	..	3·8
14	16 to 22 October	..	15·0	..	7·0	..	8·2	..	..	..	4·9	..	0·18
15	23 to 29 October	5·11	6·9	9·52	2·1	4·03	6·0	..	..	2·55	4·9	1·5	..
16	30 Ooctober to 6 November	..	9·4	..	..	..	0·9	..	..	..	4·9	..	0·4
17	6 to 12 November	..	2·6	..	..	..	1·3	..	..	..	1·6	..	..
18	13 to 19 November	..	1·7	..	..	..	0·5	..	..	..	4·9	..	..
19	20 to 26 November	..	2·1	..	..	..	0·2	..	..	..	1·6	..	..
20	26 November to 3 December	..	0·9	1·06	..	..	0·6	..	..	..	4·9	..	..
21	4 to 10 December	..	1·1	..	..	..	0·4	..	..	..	1·6	..	..
22	11 to 17 December	..	0·1	..	..	..	0·1	..	..	..	..	..	..
23	18 to 24 December	..	..	..	..	..	..	..	..	..	..	..	..
24	25 December and onwards	..	..	..	..	..	..	..	..	..	..	..	..
	Total drop (number)	..	1,676	..	287	..	2,568				61		235
	Total harvest	..	2,062	..	*Nil*		7,802				1,237		80
	Total fruiting	..	3,738		287		10,370				1,298		315
	Percentage of drop		44·8		100		24·8				4·7		74·6

While survey of the growing tracts was being made, premature dropping of citrus fruits was noted throughout Bihar. Districts of Ranchi, Palamau, Singhbhum, Gaya and Muzaffarpur were found to suffer the most. All varieties of sweet types of oranges, sweet limes, and *kagzi* limes were equally affected. It was also noticed that some dropped fruits were affected with diseases and pests. The extent of damage was so great that a special study of the factors affecting it was made and control measures sought.

Materials

These studies were made on Nagpur oranges grown at Government Farms in Chianki (Palamau), Bikramganj (Shahabad), Jamui (Monghyr) and Nawadah (Gaya), situated in different parts of the province, where better facilities for control and studies were available. The trees at these places were between 10 to 15 years old. Observations were recorded on 10 fruiting Nagpur orange trees of the same age at each of the above farms. The trees were put under identical cultural treatments.

Observations and results

It may be mentioned here that the citrus trees bloom twice a year, one in February-March called *ambe-bahar* which fruits are harvested in December and January and another in June-July called *mrig-bahar*, the fruits of which are ready in April. The extent of one bloom usually depends on the size of the other. In Bihar generally the *ambe-bahar* fruits are more.

The period of observations ranged from the first of August when the fruits have developed to some extent (4 cm.) up to the harvest i.e. in December.

Daily drops from each tree and the number of fruits cracked and split, as well as insect attacked and diseased, were recorded. The data are presented in Table V.

It will be seen that the intensity of dropping varied from place to place and year to year [Coit and Hodgson, 1916; 1918; 1919]. Drops were most severe at Bikramganj, with Nawada, Jamui and Chianki following in order. At all places except Chianki Farm in Palamau District dropping starts almost at the same time, during mid-August, and reaches maximum during the third week of September and then suddenly drops down towards minimum during last week of October. In Chianki Farm the maximum dropping has been observed in the first week of August. The fall towards minimum was recorded earliest at Chianki and Jamui during first week of October and a week later at Bikramganj and latest at Nawadah by the first week of November.

The climatic conditions of the respective places have direct relation with the phenomenon. This confirms the findings of [Coit and Hodgson 1916; 1918; 1919]. Monsoon breaks and closes earlier at Chianki than at other

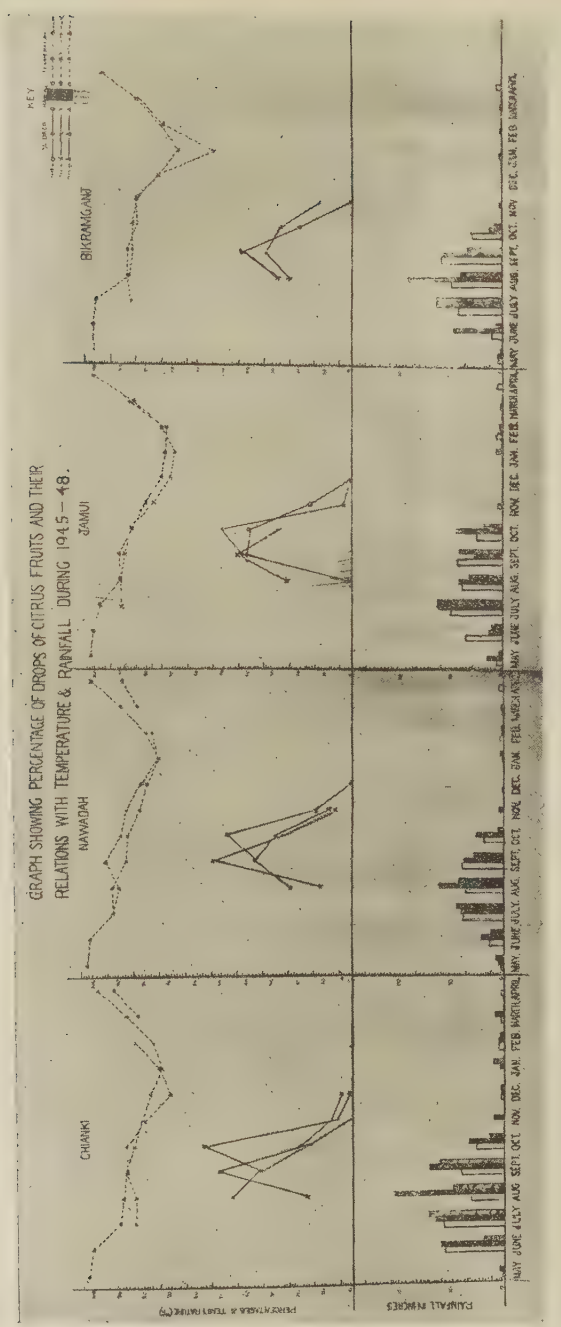

FIG. 1. Percentage of drops of citrus fruits and their relations with temperature and rainfall during 1945-48

places. The intensity of premature dropping also reaches maximum and falls towards minimum earlier at this place than others (Table V). It will also be seen from the data presented that Nagpur oranges show alternate bearing habit like mangoes, and that during 'off' years more fruits have dropped. Thus, it may be noted that percentage of drops was higher at Bikramganj during 1945-46 and 1947-48 and Jamui during 1946-47, the 'off' years for the plants under observation. The occurrence of more drops during 'off' years than during 'on' years is due to the fact that the trees had exhausted their food materials after a full bearing and the soil is depleted of the nutrients.

To find out if any co-relation existed between weather conditions and percentage drop data on rainfall, number of rainy days and the maximum temperature have been collected in all the farms, as is shown in the Plate XX.

Total annual rainfall and monthly precipitation have been found to vary from place to place but mostly during the months from July to October there were heaviest showers. Of the normal yearly rainfall of 58, 35, 44 and 50 inches at Chianki, Nawadah, Jamui and Bikramganj respectively, the total precipitation during these four months have been noted to be 57, 35, 37 and 47 inches in 1946 and 41, 26, 33, 30 inches in 1947. Thus direct co-relation of the dropping of fruits with the rainfall conditions may be established from the fact that the period of maximum intensity of premature dropping coincides with the length of duration of maximum precipitation or with higher rainfall [Coit and Hodgson, 1918].

It may also be observed that the extent of premature dropping during a month varies as the amount of precipitation during the previous month ; and as the soil becomes drier towards the end of monsoon, the intensity of premature drops also becomes less and less.

The number of drops comes to the minimum as soon as the land has drained off all the surplus water during the last week of October when the weather conditions have practically changed towards winter. Mention has been made before that the extent of drop is more during the 'off' years but Chianki Farm (Table V) had shown dropping more in 'on' year in 1946-47. During this year the monsoon at that place prolonged unusually till November which had a direct effect in increasing the premature fruit drop of the plants in that farm.

From the results of the earlier observations regarding the lesser intensity of drop during the cooler period of the year after October, it was thought that the change in the flowering season from *ambe-bahar* to *mrig-bahar* may be advantageously used in minimising the fruit drop. So a number of plants were treated for inducing *mrig-bahar* in Chianki, Nawadah and Jamui Farms during 1945. The number of plants put under observations was 100, 15 and 10 respectively in the above farms. It was found that the fruits developing from *mrig-bahar* showed little or no drop. To confirm these observations experiments were laid out at Chainki Farm during 1946-47 and 1947-48 with two similar sets of trees. Observations were recorded weekly and the data are presented in Table VI.

TABLE VI

Premature drop of Nagpur oranges at Chianki Farm of mrig-bahar.

Period	1946-47		1947-48		
	Total drop of 10 trees	Percentage drop of total	Period	Total drop of 10 trees	Percentage drop of total
1 to 7 October	8	2·5	..		..
8 to 14 October	21	6·6	..		..
15 to 21 October	12	3·8	..		..
22 to 28 October	13	4·1	..		..
29 October to 4 November	1	0·3	..		..
5 to 11 November	0	0·0	..		..
12 to 18 November	1	0·3	..		..
19 to 25 November	5	1·6	..		..
26 to 2 December	78	24·4	..		..
3 to 9 December	2	0·6	..		..
10 to 16 December	3	0·9	..		..
17 to 23 December	5	1·6	..		..
24 to 30 December	52	16·3	..		..
31 December to 6 January	5	1·6	..		..
7 to 13 January	11	3·4	..		..
14 to 20 January	11	3·4	..		..
21 to 27 January	18	5·6	..		..
28 January to 3 February	6	1·9	1 to 7 February	24	29·2
4 to 10 February	8	2·5	8 to 14 February	20	24·3
11 to 17 February	23	7·2	15 to 21 February	20	24·3
18 to 24 February	15	4·7	22 to 28 February	17	20·7
25 February to 3 March	22	6·9	29 to 4 March	1	1·2
Onwards	0	0·0	Onwards	0	0·0
Total drop	320	(100)		82	100
Total insect attack	85	26·5		0	0
Harvest	5,942			1,273	
Percentage of drop	5·0			6·05	

August 1947 to January 1948, no drop

The percentage of premature drops recorded in 1946-47 was 48 in fruits developing from *ambe-bahar* and 5 from *mrig-bahar* (Tables V and VI), and in 1947-48, 12·9 and 6 respectively. So it is seen that the premature dropping of fruits of *ambe-bahar* is much more than those developing from *mrig-bahar* which is due to the fruits of the former, setting in hot weather and developing in monsoon, while those of the later set in rains and develop during the cool and dry weather in winter [Webber and Batchelor, 1948].

Varieties affected

As mentioned before, Nagpur or loose skinned variety predominates in South Bihar and Chhotanagpur areas. A report was received during 1945-46 that drops in loose skinned varieties was higher than in tight skinned ones. To confirm that, observations on Malta orange trees grown in Jamui and Newada Farms were carried out during 1946-47 and 1947-48. Ten Malta orange trees grown under similar condition were selected at these two farms. It will appear from the Table VII that tight skinned oranges were more severely affected than loose skinned ones.

TABLE VII

Comparative observations of total drops (of ten trees) of loose-skinned and tight-skinned oranges

	Jamui Farm				Nawadam Farm			
	Nagpur		Malta		Nagpur		Malta	
	1946-47	1947-48	1946-47	1947-48	1946-47	1947-48	1946-47	1947-48
Total drops	287	2,568	155	929	2,174	1,036	245	821
Percentage of harvest	100·0	24·8	76·0	89·1	36·0	40·9	74·9	86·1

DISCUSSION

Shedding of fruits may be due to adverse climatic conditions, unfavourable water supply and nutrition, or by injuries caused by insect and fungi. Two or more of these factors may often be operating together or one following the other, so that it is difficult to separate their effects. More important are unfavourable conditions of climate and weather. Webber and Batchelor [1948] point out that June drops are increased by deficiency of nitrates which is generally the case in plants in Bihar in the 'off' season. They also point out that drop may take heavy toll especially when abnormal hot weather occurs soon after the blooming period. This has also been observed in the case of flowering generally followed by the hot weather of March to June when strong westerly winds are prevalent in Bihar. In South

Africa, Wager [1939] working with a similar problem judged that excessive drop is the result of harsh temperature, low humidity and strong wind. In a preliminary experiment conducted by [Stewart, Klotz and Hield, 1947] spraying with growth regulating materials for checking of the drop of both immature and mature fruits, has been found to be encouraging.

Some believe that a fairly liberal supply of available nitrogen in spring is desirable for citrus trees in order to provide for their needs during the blooming and fruit setting periods. It is probable that young fruits grow faster on well nourished trees and consequently are less susceptible to drop.

Coit and Hodgson [1916; 1918 ; 1919] point out that unless there exists in the soil within the reach of the absorbing roots a water supply sufficient to make up for that lost by the plant, a water deficit must eventually occur which will be followed by an abnormal shedding of the young fruits. During April to June, the hottest part of the year in Bihar, the soil becomes parched and the prevalent high dry wind force the trees to transpire abundantly through their new leaves, thereby making the demand for water greater than the absorbing and conducting system of the plants can possibly supply. In early summer this stress is reflected in an excessive shedding of the young fruits [Kinnison and Finch, 1934]. This again has been observed in an experiment at riverside, even when an adequate soil moisture supply has been available but heaviest drop there is usually associated with defficiencies in available moisture. In Bihar the maximum drop has been observed when the soil moisture and humidity are the highest during the year i.e. in September and October.

Summary

Premature drop in citrus fruits was noticed throughout the province.

Drop was more severe during 'off' years of the Nagpur orange trees than in 'on' years.

The tight-skinned Maltas were observed to be more severely affected than loose-skinned Nagpur oranges.

Dropping starts at all places during mid-August (when rainfall is higher) and reaches maximum in the third week of September. Thereafter it lessens and suddenly drops down to *nil* during last week of October.

Dropping of *ambe-bahar* fruits is much more than that of *mrig-bahar* fruits due to fruit setting and developing during the wet and dry seasons respectively.

Intensity varies with the amount of rainfall during the previous month and coincides with the length of duration of maximum precipitation.

A study of the premature drop of oranges in Bihar was made. Premature drop of citrus fruits was found to be wide spread phenomena in Bihar. Drops during the development period of the fruits was recorded at Government Farms in various parts of the province. The drop depended on the amount of rain and the number of rainy days. As the drier and colder season approaches the drops lessen. There were more drops of fruits developing from *ambe-bahar* flush (February to

March bloom, fruits ready in December to January) than from *mrig-bahar* flush (June to July bloom, fruits ready in March-April). Dropping was also observed to be more during 'off' years. It is suggested that in Bihar flowering in *mrig-bahar* should be encouraged.

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KANS GRASS (*SACCHARUM SPONTANEUM* L.) A COLLATERAL HOST FOR SUGARCANE SMUT IN INDIA

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(With Plate XXI)

SUGARCANE smut caused by *Ustilago scitaminea* Syd. is an important disease of sugarcane in India. According to Butler [1918] the fungus is said to attack *Saccharum spontaneum* L. in Java and even to spread from the latter to the cultivated crop. With regard to India, Butler [1918] states that '*S. spontaneum* and *S. fuscum* Roxb. are attacked by smuts which only differ from *U. sacchari* Rabenh., the sugarcane smut, in the spore measurements'. Butler has further stated that whether the smut commonly encountered on *Saccharum spontaneum* in India is the same as sugarcane smut or a distinct species will only be ascertained when cross inoculations are tried. Sydow [1941] named *U. sacchari* Rabenh. as *Ustilago scitaminea* and stated that it had a spore diameter of 5·5 to 7·5μ. The smut on *S. fuscum* with a spore size of 3·5 to 5μ was named by him as *Ustilago consimilis* Syd. and the smut on *Saccharum spontaneum*, the material of which came from India and was too poor to permit adequate description, was regarded by him to be intermediate between the two. Zundel [1930] reported that *U. consimilis* Syd. occurs on *Saccharum spontaneum* in Philippine Islands. As none of these pioneer investigators, or any one else in India, had tried cross inoculation tests, which are essential to ascertain whether these two smuts are the same or distinct species, it was considered necessary to undertake the investigation reported in the present paper.

Experimental results

The smut material used in the present tests was obtained from naturally infected sugarcane or *Saccharum spontaneum*. The technique used for inoculations was the same as reported by Chona [1942]. In the first instance it was considered desirable to find out whether the smut from sugarcane could infect *Saccharum spontaneum*. For this purpose during 1942-43 smut material was collected from Co. 313, growing in the mycological area and 200 spores were measured, the dimensions and frequency of which are given below :

Diameter μ.	5·3	5·9	6·3	6·6	6·9	8·2
Frequency η	4	25	7	156	3	5

Mean . . . . . .= 6·5μ

Standard deviation . . . . . .=± 0·4

The spores collected from Co.313 were spherical to globose, cinnamon brown to prouts brown, uniformly thick walled, and with minute echinulations.

Thirty-six one-eye setts of *Saccharum spontaneum* were treated with the smut spore suspension made from the above Co.313 material. These were then planted in pots and observations on germination, smut development and incidence were recorded weekly. The results are summarized in Table I. No case of smut was found to develop in the controls. Plate XXI, fig. 1 shows a shoot from a clump of *S. spontaneum* which developed smut as a result of inoculation.

TABLE I

Results of cross inoculations

Host variety inoculated	Source of smut inoculum	Number of setts treated and planted	Number of clumps established	Number of clumps that developed smut	Smut infection per cent
Saccharum spontaneum Co. 313	Smut material from Co. 313	36	15	10	66
	Smut material from artificially inoculated *Saccharum spontaneum*	30	28	14	50
Co. 312	do.	20	14	12	85
Co. 312	Smut material from *S. spontaneum* found infected with smut in nature	10	8	6	75
Co. 313	do.	10	8	6	75

In the second series of cross inoculation tests during 1943-44, smut material from *S. spontaneum*, which had developed smut as a result of inoculation with smut material from Co.313 in the previous season, was used as inoculum. The spore measurement analysis of two hundred spores of this material is given below:

Diameter μ	5·9	6·3	6·6	6·9	7·3
Frequency η	13	7	168	8	4

Mean .= 6·6μ

Standard deviation .=± 0·3

In size, shape, colour and wall markings these spores were found identical with the Co. 313 smut used as inoculum.

Spore suspension from the smut material was made as usual, and 30 one-eye setts of Co. 312 and 313 each, selected from smut free seed cane material, were treated with the spore suspension and planted in pots. Observations on the smut

FIG. 1. A shoot from a clump of *Seacharum spontaneum* infected with sugarcane smut as a result of inoculation showing two typical culmicolus smut whips

development in the resulting crop were recorded and are set out in Table I. Cane varieties Co.313 and Co.312 developed 50 per cent and 85 per cent smut infection respectively as a result of inoculation with the smut from artificially inoculated *S. spontaneum.*

Spore measurement data of the smut material of Co.313 successfully inoculated with smut material from artificially inoculated *S. spontaneum* are as follows:

Diameter μ	5·3	5·9	6·6	7·2	8·2	
Frequency η	9	49	130	10	2	
Mean					.=	6·4μ
Standard deviation					.=±	0·4

In July 1948, *S. spontaneum*, growing wild in the agricultural farm at the I.A.R.I. was found severely infected with a culmicolous smut closely resembling, in all its symptoms, with sugarcane smut, under natural conditions. The smut has again been observed on *S. spontaneum* this year, in May 1949, in that very plot. The spore measurements of the smut from this *S. spontaneum* are given below:

Diameter μ	4·9	5·7	6·6	7·4	
Frequency η	28	31	124	17	
Mean				.=	6·3μ
Standard deviation				.=±	0·3

The spores were spherical to globose, Dresdon to cinnamon brown, uniformly moderately thick walled and finely echinulate.

Ten one-eye setts of each of the cane varieties Co.312 and Co.313 were dipped in the spore suspension prepared from the smut mate infected *S. spontaneum* and planted in pots. The observations on smut development in the resulting plants are summarised in Table I. Co.312 and Co.313 developed 75 per cent infection. The spore measurements of this material from Co.313 are as follows:

Diameter μ	4·9	5·7	6·6	7·4	
Frequency η	9	43	146	2	
Mean				.=	6·3μ
Standard deviation				.=±	0·4

From the results reported it is evident that the smut from sugarcane can be successfully transmitted to *S. spontaneum.* The smut whips produced on *S. spontaneum* resemble those produced on cane, as both of them are culmicolous. The spores in both the cases are identical. It has further been established that the smut from artificially inoculated *S. spontaneum* can be transmitted back to sugarcane from which the original inoculum was taken.

The smut from *S. spontaneum*, found infected in nature, was found to be in identical with the sugarcane smut in spore size, symptoms on host and spore morphology except the colour of the spores, which was Dresden brown to cinnamon

brown, and successfully infected Co.312 and Co.313. The spores produced on the whips of the infected cane plants were found to be identical with the spores of naturally smutted *S. spontaneum*, showing thereby that no change in the *spontaneum* smut had occurred as a result of its passage through sugarcane.

In view of the above findings, it is concluded that the smut on *S. spontaneum* is identical with the smut found on sugarcane in its morphology and pathogenicity. These results are of considerable practical importance, as they show that the *S. spontaneum* can act as a collateral host of sugarcane smut and consequently prove a source of infection for the cultivated varieties of sugarcane. Necessary care, therefore, should be taken to rogue out, from the neighbourhood of cane fields, any cases of *S. spontaneum* affected with smut in nature, to safeguard the sugarcane crop against smut.

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STUDIES ON THE DISEASES OF SUGARCANE IN INDIA

III. SOURCES AND MODES OF RED ROT INFECTION

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(With Plates XXII—XXIII)

RED rot of sugarcane, caused by *Colletotrichum falcatum* Went, is by far the most important disease of sugarcane crop in India. According to Butler [1918] red rot has often been the limiting factor in the successful cultivation of heavy yielding canes, such as would enable India to hold its own against other sugar producing countries, like Java and Mauritius. The havoc that the red rot epidemic caused in recent years (1938 to 1941), to the cane crop in Northern India white-sugar belt, resulting in the widespread failure of Co.213, the chief commercial cane variety of the tract, clearly brings home the true significance of the disease. Several sugar factories in the badly affected areas of the Eastern United Provinces could crush only one-third of their normal ' crush ' of cane during 1938-39 owing to poor supplies. The estimated loss of 75,000 tons in the sugar production in India that season has been ascribed, unanimously, to the ravages of red rot. During 1939-40 the position was only slightly better. By 1941, although the epidemic was successfully controlled in Northern Bihar and was showing a decline in Eastern United Provinces, it had spread to other cane tracts in Bengal, Orissa, South Bihar, certain parts of the Central and Western United Provinces and eastern districts of the Punjab. Co.213 was the variety worst affected at all the places but red rot infaction, to an appreciable extent, was observed in Co.299 and Co.331, which subsequently, completely went down with red rot. Stray cases of red rot were observed in several other varieties also including the two important economic canes of the United Provinces and Bihar namely, Co.312 and Co.356. Since the last two or three seasons (1946 to 1949) the red rot epidemic has agian flared up in Eastern United Provinces and severely affected the two cane varieties, Co.312 and ' Mamchuah ', now widely grown in the tract. Co.312 has also been found affected badly in certain areas of Central and Western United Provinces.

Such a sudden and complete failure of Co.213, the cane variety which had faithfully served the cane-sugar industry of India for nearly one decade, over such a wide area in a tract where it had flourished for several years, was certainly not without surprise. Also the going down, with red rot, of other important commercial varieties like Co.299, 312, 331 after two or three seasons of wide scale cultivation

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in the affected areas previously under Co.213. It raises many questions of fundamental importance as to the sources and modes of infection of the disease, its spread and perpetuation. Careful examination of thousands of canes in different localities in the epidemic areas clearly revealed that the recent red rot epidemic could not be ascribed to the use of diseased cane setts alone, as was the view of Butler [1906] who claimed that the use of healthy setts completely controlled the disease. This has given rise to our conventional views of ' clean setts and no red rot '. Examination of the diseased canes in the epidemic areas, as reported in an earlier publication, Chona and Padwick [1942], had clearly revealed the presence of considerable secondary infection in the upper and middle portions of the canes in the *entire absence* of any basal infection, originating from the diseased setts, strongly indicated that some other factors were also operating.

The present investigation was, therefore, undertaken with these objects in view and the information obtained on the sources and modes of infection of the disease is presented in this paper.

Materials and methods

The seed cane material of the various cane varieties used in these experiments was obtained originally from the Cane Breeding Station, Coimbatore, to ensure their true identity and was always multiplied in special seed plots whose crop was frequently examined throughout the preceding season and kept free from red rot or any other serious cane disease, to ensure the use of guaranteed disease-free seed and material for experimental purposes.

The red rot inoculum consisted either of the pure cultures of the light type, highly virulent, *Colletotrichum falcatum* (Isolate 78) which was originally obtained from the red rot affected canes collected from the epidemic areas of Eastern United Provinces and Northern Bihar, or the red rot affected canes from epidemic areas (or from our experimental plots) chopped up into small pieces. In a few comparative tests, the dark type *C. falcatum* (Isolate 3) and *C. falcatum* (Isolate 29), isolated from ' *Shahabad Ponda* ', a thick ' Noble ' cane variety (*Saccharum officinarum* type), were also used. The cultures were maintained on oat meal agar and were started off as single spore or single hyphal-tip cultures to ensure their purity. The experiments were conducted mostly out in the field at Karnal or Delhi in plots far away from any other cane fields in the neighbourhood. Re-isolations were frequently made from the successfully infected canes to ascertain that the infection had really been caused by the experimental inoculum.

The land of these experimental plots is a light loam at Delhi and heavy clayey-loam at Karnal. Three years' rotation was strictly followed and the cane plantings were always preceded by keeping the plot fallow for about one year. The fields were always well prepared and manured with farm yard manure at the rate of 10 cart loads per acre, or powdered mustard cake, at the rate of 10 md. per acre, applied in two equal doses : half at the time of planting (March-April) and the other half at the time of earthing up in June or July. Besides, the cane plots at Karnal were green-manured as well. The rows were 3 ft. apart, usually 25 ft. to 30 ft. long

and about 25 to 30 setts (3-eye) were planted in each row. The crop was grown under irrigated conditions and it usually received about 12 to 15 irrigations during the season. Suitable bunds and irrigation and drainage channels were made for experimental plots so that there was no chance of any overflow of irrigation or rain water from one plot to another. Necessary care was also taken during weeding and other cultural operations to safeguard against any infection being carried from plot to plot.

Experimental results

Sources of infection

(a) *Soil infection*

(i) *Red rot affected cane debris in the soil.* To study the role of red rot affected cane debris in the soil as source of infection, several experiments were carried out from 1939 to 1945 at Delhi and Karnal. The results of a few preliminary experiments, carried out at Delhi during 1939 to 1941, indicating the possibility of red rot infection through soil, have been reported already [Chona and Padwick, 1942].

In an experiment on the role of soil infection in relation to red rot, conducted at Karnal, red rot affected canes (Co.213) obtained from the United Provinces red rot epidemic areas (Lakhsar, Bareilly, Nawabganj, Gonda) were chopped into small pieces and liberally applied in 27 furrows, which were then planted (on 7 April 1941) with Co.213, 223, 299, 312, 313, 331, 419, 421 and 445. Three 30 ft. rows, with thirty three 3-eye setts in each, were planted with each of the nine varieties, and observed for red rot development. Germination was rather poor in Co.213, 223, 299 and 445, owing to the rotting of the seed setts with red rot. Cases of red rot infection were observed during August and September, 1941 in Co.213, 223, 299, 331 and 445, which were rogued out soon after their appearance to avoid secondary infection. At harvest time (April 1942) all the standing canes in these rows were cut, split open longitudinally and examined. Co.213, 223, 299, and 445 had developed red rot infection to the extent of 28·3, 27, 34·5 and 10·9 per cent respectively.

The experiment was repeated during 1942-43, using red rot cane debris from the canes which had been inoculated during the previous season (1941-42) with *C. falcatum* (isolate 78). Red rot infection to the extent of 44, 73, 91 and 79 per cent had developed in Co.213, 223, 299, and 331 respectively by the end of the season (April 1943). No case of red rot infection was observed in the controls.

Similar results were obtained in soil-infection experiments conducted during 1943-44 and 1944-45, the red rot infection, that developed, being 96·6, 62·6, 76, 8·7 and 55·5 per cent in Co.213, 223, 299, 313 and 331 respectively during 1943-44 and being 30·7, 8·3 and 66·6 per cent in Co.213, 223 and 299 respectively during 1944-45.

One of the soil-infection experiments was started in September 1943 at Delhi, to study the development of red rot through soil-infection in September-planted crop. By the harvest time, i.e. March 1945, Co.223, 299 and 445 showed 50, 93 and 42 per cent red rot infection respectively.

In one of the soil infection experiments at Karnal, during 1941-42, in which red rot cane debris from canes inoculated with the dark type *C. falcatum* (isolate 3) during the previous season was used as inoculum in the furrows, and planted with Co.213, 223, 299, 312, 313, 331, 419, 421 and 445 ; Co.213 showed no infection while Co.223 and 299 developed 0·5 and 3 per cent infection respectively. These figures as compared to the infection of these three varieties with isolate 78 (i.e. 38·3, 27 and 34·5 per cent) during the same season at Karnal clearly indicated the greater virulence of the light type *C. falcatum*.

The results obtained in one of the typical soil infection experiments with red rot affected cane debris, conducted at Karnal, are presented in Table I.

TABLE I

Red rot development in soil infected with red rot cane debris from the United Provinces epidemic tract at Karnal, 1941-42

Cane variety	Number of setts planted	Total number of tillers (14-8-1941)	Number of shoots affected with red rot						
			August 1941	September 1941	Total	Per cent infection	*Final observation (April 1942)*		
							Total number of canes	Number affected	Per cent infection
Co. 213	100	172	8	3	11	6·3	239	68	28·3
Co. 223	100	226	3	1	4	1·6	241	64	27·0
Co. 299	100	53	6	1	7	13·2	113	39	34·5
Co. 312	100	116	0	0	0	0·0	161	0	0·0
Co. 313	100	182	0	0	0	0·0	213	0	0·0
Co. 331	100	170	1	0	1	0·6	247	1	0·4
Co. 419	100	124	0	0	0	0·0	145	0	0·0
Co. 421	100	114	0	0	0	0·0	184	1	0·5
Co. 445	100	171	2	2	4	2·4	285	31	10·9

(ii) C. falcatum *spores and mycelium in the soil*. In these soil infection experiments the red rot inoculum consisted of pure cultures of *C. falcatum* (isolate 78), growing on oat meal agar, producing vigorous growth and abundant sporulation instead of red rot affected cane debris. The cultures were made into a suspension in water which was uniformly mixed with finely sieved soil and applied liberally in the furrows which were then planted with the desired cane varieties and observed for red rot development.

During 1941-42, in an experiment conducted at Delhi, cultures of *C. falcatum*, light type isolated from the United Provinces and Bihar epidemic areas, were used as inoculum to infect the furrows which were then planted (March 1941) with 50 setts each of Co.213, 299, 312, 313, 331 and 419. By harvest time (15 February

1942), when all the canes in these experimental rows were cut and examined, Co.213 and 299 showed 42 and 60 per cent infection respectively. A few cases of red rot were observed in Co.312, 419 and 331 also ; the incidence being 8, 5 and 2 per cent respectively.

In a similar experiment during 1941-42 at Karnal with nine cane varieties namely, Co.213, 223, 299, 312, 313, 331, 419, 421, and 445, where pure cultures of *C. falcatum* (isolate 78) were used for giving infection in the furrows, Co.213, 223 and 299 developed red rot infection to the extent of 33, 10 and 73 per cent respectively. The controls remained completely free from red rot. The number of setts planted with each variety was 50. The red rot infection in the remaining six varieties ranged from 0 to 1·7 per cent.

The experiment was repeated during 1942-43 at Karnal and the figures for red rot infection observed in Co.213, 223, 299 and 331 were 94, 9, 100 and 62 per cent respectively.

In some of such soil infection experiments with pure cultures of *colletotrichum*, where the dark, sparsely sporing type of *C. falcatum* (isolate 3) was used as inoculum, no red rot infection was obtained.

Data of a typical experiment, where pure cultures of *C. falcatum* (isolate 78) have been used as inoculum to infect the soil, are presented in Table II.

TABLE II

Red rot development in soil infected with C. falcatum *(isolate 78) cultures at Delhi during 1941-42*

Cane variety	Number of setts planted	Total number of tillers (14-8-1941)	Number of shoots affected with red rot							
			August 1941	September 1941	November 1941	Total	Per cent infection	Final observation (February 1942)		
								Total number of canes	Number affected	Per cent infection
Co. 213	20	205	3	15	25	43	21	137	57	42
Co. 299	50	75	0	3	17	20	27	63	38	60
Co. 312	50	181	1	0	0	1	0·6	168	13	8
Co. 313	50	186	0	0	0	0	0·0	104	2	2
Co. 331	50	177	0	1	0	1	0·6	108	0	0
Co. 419	50	105	1	0	4	5	4·8	82	4	5

(iii) *Soil from red rot affected fields.* In one of the experiments at Karnal during 1943-44, healthy setts of Co.213 223, 299 and 331 were planted in a field whose soil had been mixed with soil from a plot having heavily red rot infected crop. The soil, used as inoculum, was collected from the neighbourhood of diseased clumps. The resulting crop developed red rot infection to the extent of 7·1 and 4·3 per cent

in Co.213 and 223 respectively. The practical importance of the finding is obvious : it indicates the role of infected soil transferred, through floods and erosin, from diseased plots to healthy fields.

It is obvious that even healthy cane material when planted in soil containing *C. falcatum* infection does not produce a red rot-free crop and that soil infection can play an important role in the infection, spread and prepetuation of the disease. There are also clear indications that certain cane varieties, like Co.313 and 421 show greater resistance to soil infection. Such cane varieties may, thus, escape the disease despite the presence of red rot inoculum in the soil. Red rot in the soil has been found to appreciably affect the germination owing to the rotting of the seed setts. This pre-germinal injury is more marked in the case of cane varieties that are comparatively more susceptible to red rot.

(iv) *Survival of red rot infection in the soil.* The role of soil infection in bringing about red rot having been clearly established, the most important point, from practical point of view, that suggests itself is the study of survival of red rot organism in the soil. All the attempts at direct isolation of *C. falcatum* from infected soil having remained unsuccessful, it was decided to use cane varieties, highly susceptible to red rot, to detect the presence of the red rot infection in soil.

In one such experiments, during 1941-42, at Karnal, red rot affected canes (Co.213), obtained from red rot epidemic areas, were chopped up into small pieces and applied liberally in the furrows in a plot (90 ft. × 30 ft.) at Karnal. The plot was divided into three subplots, of which one was planted with Co.213, 223, and 299 immediately after giving the infection (on 7-4-41) ; the second was planted on 31 August 1941 and the third in May, 1942 (i.e. about five months and thirteen months after giving the infection) with the same three varieties. Hundred setts of each variety were planted in three rows. Severe red rot infection was obtained in the plot planted in April, the infection being 28, 26 and 36 per cent in Co.213, 223 and 299, respectively, at the harvest time (April 1942). No case of red rot was observed in the two later plantings.

The experiment was repeated during 1942-43 with Co.213, 223, 299, 231 and 373, using the infected portions of the canes previously inoculated with *C. falcatum* (isolate 78) as the cane debris for infection. In the plot where planting was done immediately after giving the infection (i.e. April, 1942) heavy red rot infection resulted in all the five varieties ; but no infection occurred in the other two plots, planted five months and eleven months after infecting the soil.

Experiments carried out during 1943-44 and 1944-45 at Karnal confirmed the previous findings.

Similar results were also obtained when pure cultures of *C. falcatum* (isolate 78) were used as inoculum instead of cane debris for infecting the soil.

Experiments along these lines were carried out at Delhi also during 1941-42, 1942-43, and 1943-44 and the results obtained were, generally speaking, in agreement with those obtained at Karnal. In one of these experiments at Delhi the plantings were done at monthly intervals after infecting the soil and it was found that the infection in the soil fell off rather rapidly.

In order to study the survival of red rot infection in the soil under winter conditions, in one of such experiments at Delhi, the red rot cane debris was applied to the plots in November 1944. One of the plots was planted immediately after giving the infection ; the second a month later and the third five months after infecting the soil. The cane variety planted was Co.213. By the harvest time, i.e. March 1945 the cane crop in these plots developed 54, 12 and 1 per cent infection respectively.

Red rot infected canes (Co.213), stored in the laboratory at room temperature (27 to 32°C.), from which the causal organism was readily isolated, at the time of storage, failed to yield *C. falcatum*, after three months.

The data presented show that the red rot infection in the soil, whether in the form of cane debris or spores and mycelium, is only short-lived. But considering that the cane crop of one season overlaps that of the next ; that ratoons are frequently kept ; and that October-planting of cane is practised in many tracts, there is a possibility of perpetual soil infection.

(b) *Sett infection*

(i) *Setts artificially infected with* C. falcatum. Seventy-five 3-eye setts of Co.213, 223, 299, 312, 313, 331, 419, 421 and 445 were soaked in water overnight and were then inoculated in the middle, by plug method of Grainger and Horne [1924], with young vigorously growing cultures of *C. falcatum* (isolate 78). The inoculated setts were incubated under highly humid conditions for forty-eight hours and were then planted in the field at Karnal in March 1941 to study red rot development. In the case of controls, 25 setts of each of the nine varieties, were treated in exactly the same way except that sterile oat meal agar was given as inoculum instead of *C. falcatum*. While no case of red rot was observed in the controls, severe red rot infection developed in Co.213, 223, 299 and 331 crop. By harvest time, (April 1942) the incidence of red rot infection observed in these four varieties was 66, 19, 83, and 40 per cent respectively. Co.445 also showed an infection of 33 per cent at the harvest time. In the remaining four varieties the infection obtained varied from 0·8 to 3 per cent.

The experiment was repeated during 1942-43 at Karnal. Healthy setts of Co.213, 223, 299, 313, 331, 356, 419 and 421 inoculated with *C. falcatum* (isolate 78) developed red rot infection in the resulting crop to the extent of 95, 58, 100 and 68 per cent in Co.213, 223, 299 and 331 respectively. Setts of Co.313, 356, and 419, though similarly treated, failed to develop any infection ; and Co.421 gave only two per cent infection. The experiment was again repeated at Karnal during 1943-44 with similar results.

In a similar experiment of sett infection, carried out at Karnal during 1941-42, where the dark type *C. falcatum* (isolate 3) was used as inoculum the red rot infection that developed was much less ; being only 4·5 per cent in Co.213 and one per cent in Co.223.

Similar experiments were carried out at Delhi with Co.213, 299, 312, 313, 331 and 419 during 1941-42, using both the light and the dark type of *C. falcatum* (isolates 78 and 3) for inoculating the setts, and the results obtained were in accordance with those obtained at Karnal i.e. Co.299 showed the greatest amount of infection ;

Co.213 being the next in order ; and the light type of *C. falcatum* (isolate 78) proving much more virulent than the dark type (isolate 3).

Data of one of such experiments, where the setts are inoculated with *C. falcatum* prior to planting are presented in Table III.

TABLE III

Red rot infection in cane crop planted with setts inoculated with light type C. falcatum *(isolate 78) at Karnal during 1941-42*

Cane variety	Number of setts planted	Total number of tillers (14-8-1942)	Number of shoots affected with red rot						
			August 1941	September 1941	Total	Final observation (April 1942)			
						Per cent infection	Number of canes	Number affected	Per cent infection
Co. 213	75	263	32	21	53	20	199	133	66
Co. 223	75	138	1	0	0	0·6	282	52	19
Co. 299	75	157	26	15	41	2·5	96	80	83
Co. 312	75	155	4	1	5	3	223	0	0
Co. 313	75	192	0	0	0	0	361	3	08
Co. 331	75	128	35	17	52	40	160	63	40
Co. 419	75	145	0	0	0	0	130	4	3
Co. 421	75	151	0	0	0	0	173	5	3
Co.445	75	100	2	0	2	2	136	46	33

(ii) *Naturally diseased setts.* In these experiments red rot affected canes were cut into 3-eye setts and only such setts that showed reddening at one or both ends were planted and observed for red rot development. In one such experiment diseased setts from red rot affected canes of Co.213, obtained from epidemic tract of the United Provinces, were planted at Karnal in April 1941. The germination and stand of the resulting crop was very poor. A few cases of red rot were observed during the following September and December. At the close of the experiment, at harvest time (April 1941), about 25 per cent of the crop was found affected with red rot. The experiment was repeated in 1942-43 and 1943-44 with similar results. The infection in the resulting crop, however, varied from 20 to 78 per cent.

The results of three to four seasons with red rot infected setts, artificially inoculated or naturally infected, show that considerable red rot infection can occur by planting diseased setts, particularly in cane varieties tested i.e. Co.213, 223, 299, 331. Also that the light type *C. falcatum* (isolate 78) is much more virulent than the dark type. Disease lesions could be invariably traced passing from the diseased mother setts to the shoots. The absence of the transmission of the disease, or its presence only in traces, inspite of the setts planted being infected, in varieties like Co.313, 419 and 421, is of particular interest and throws some light on the controversial findings of Butler [1906], Butler and Hafiz Khan [1913] and Kulkarni [1911]

Fig. 1. A Co. 299 cane from a plot infected with *C. falcatum* (isolate 78) spores in irrigation water, showing red rot infection through the nodal region, near ground level

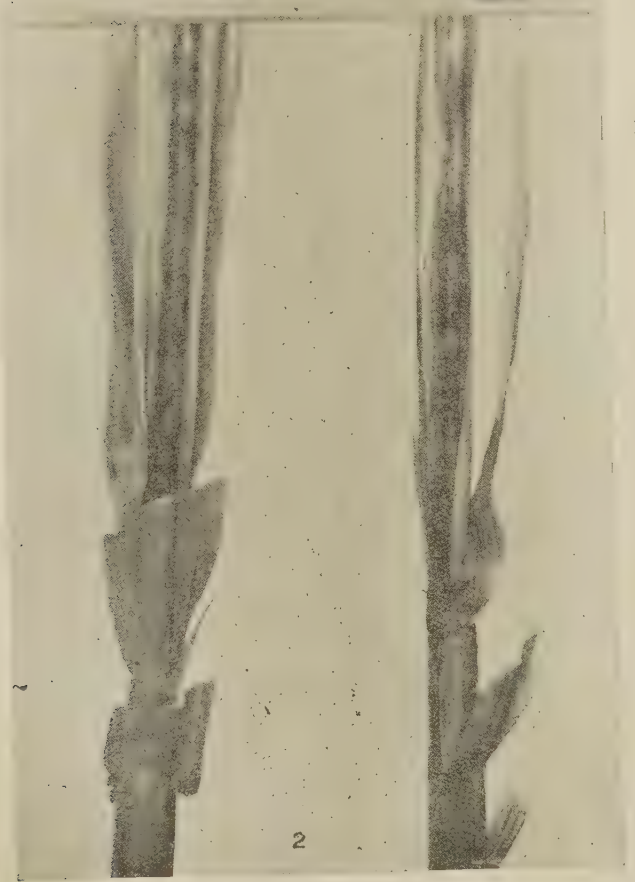

Fig. 2. A young internode of Co. 299, showing numerous *C. falcatum* acervuli breaking through the rind

Fig. 3. Young cane shoots of a clump originating from red rot affected sett, showing spindle type of *C. falcatum* mid-rib lesions

on one hand in India, who claimed that it is the setts themselves that carry the disease, and those of Edgerton [1911], South and Dunlop [1913] and Abbot [1938] on the other, who considered that no infection took place through planted setts and that the infection did not pass from the diseased mother setts to the shoots. These divergent results were apparently due to different cane varieties used in their experiments. This possibility was suggested by Edgerton and Moreland [1920] and has been confirmed experimentally during this investiagation.

(c) *Irrigation water containing red rot infection*

To study whether irrigation water containing spores of *C. falcatum* could be a source of infection, a small plot (30 ft. × 30 ft.) at Karnal having one row each of Co.213, 223, 299, 312, 313. 331, 419, 421 and 445, free from any trace of red rot, was given a heavy dose of red rot inoculum along with irrigation water during the third week of September 1941. Young vigorously growing cultures of *C. falcatum*, isolate 78 were mixed with a bucketful of water and the suspension was sprinkled at the base of the cane clumps, as uniformly as possible, in all the nine rows. The plot was then irrigated to its full capacity so that the ridges were well covered and the irrigation water was freely touching the basal portion of the canes. The inoculum was repeated six days later and the plot was again liberally irrigated. A third dose of the inoculum was given during the second week of October. The plot was frequently irrigated thereafter. The adjoining plot having one row each of the same nine cane varieties, was given all the corresponding irrigations but without *C. falcatum* inoculum, to serve as control. By December 1941 in the infected plot a few cases of red rot appeared in Co.213 and 299. At harvest time (April 1942) all the canes in these rows were cut and split open longitudinally and examined for red rot infection. Co.213, 223, 299, and 331 showed 56, 28, 51 and 14 per cent infection respectively. The remaining five varieties showed little or no red rot infection. In the control plot, no case of red rot was observed.

The experiment was repeated during 1942-43 with ten cane varieties, but with one modification that the infection with irrigation water was given at four different periods i.e. during July, August, September and November. Considerable red rot infection developed, in all the four series, in Co.213, 223, 299 331 and 445 ; being greatest in the July lot. Furthermore that of the ten varieties under test, only one failed to develop red rot infection in the July or August series, whereas in September and November series four varieties remained free from infection. In the other varieties also, the incidence of red rot infection, though distinctly less, decreased from July to November. The controls in all cases remained healthy. The data are presented in Table IV.

The red rot infection in all these cases was found to have taken place through the nodal regions, near the ground, upto the level, where the infected irrigation water had come into contact with canes. Plate XXII, fig. 1 shows one such case of Co.299.

An experiment was conducted, along these lines, with the highly virulent isolate 78 and weakly parasitic isolate 29, simultaneously and it was found that the infection, when the virulent strain was added to the irrigation water, was much greater than

TABLE IV

Red rot infection obtained in ten cane varieties by giving infection through irrigation water during July, August, September and November, 1942, at Karnal

Cane variety	Red rot infection given in											
	July			August			September			November		
	Number of shoots inoculated	Number affected with red rot	Per cent infection	Number of shoots inoculated	Number affected with red rot	Per cent infection	Number of shoots inoculated	Number affected with red rot	Per cent infection	Number of shoots inoculated	Number affected with red rot	Per cent infection
Co. 213	103	43	42	73	23	33	80	7	9	106	7	6·5
Co. 223	96	41	43	100	13	13	84	10	11·5	77	4	5
Co. 299	55	40	73	79	6	7·5	78	14	18	86	6	7
Co. 312	127	13	10·2	102	4	3·9	82	2	2·4	81	1	1·2
Co. 313	85	5	5·8	64	2	3·1	51	0	0	78	0	0
Co. 331	121	49	40	108	19	17	66	8	12	87	6	7
Co. 356	50	0	0	56	0	0	48	0	0	42	0	0
Co. 419	57	7	12·2	29	1	3·4	41	0	0	50	0	0
Co. 421	80	13	16·2	66	2	3·0	46	0	0	72	0	0
Co. 445	78	45	57·6	61	24	39·3	18	3	16·6	93	11	11·8

in the other case, so much so, that varieties Co. 213, 223, 299 and 331 which showed 0, 2, 6, 0 per cent infection with isolate 29, indicated an infection of 54, 27, 70 and 15 per cent respectively with isolate 78. The isolate 29 was obtained from red rot affected canes of *desi ponda*, a thick cane variety of *S. officinarum* type, from Shahabad Markanda (near Ambala) where appreciable amount of red rot infection is present almost every season in the *desi ponda* crop.

From the data presented above, it is evident that red rot infection may be brought about in a healthy cane crop if the irrigation water contains the spores of the fungus. Irrigation water passing through red rot affected fields and then reaching the healthy plots may result in red rot infection. Similarly, during heavy downpours of rain, overflow of rain water from diseased fields to the adjoining healthy ones, may bring about the disease. It would be also clear from Table IV that red rot development in the crop is much greater if the inoculum, along with irrigation water, reaches the plots earlier in the season i.e. during July or August. It has been shown in the following pages that considerable amount of *C. falcatum* inoculum is produced in nature as midrib lesions during the rainy weather June to September. It was observed that infection in all these cases was effected through the nodal regions of the cane. Different cane varieties reacted differently to this type of infection. While Co. 213, 223, 299, 331 and 445 developed heavy red rot infection, Co. 356 remained completely free and Co. 313, 419 and 421 showed only slight infection. It is, therefore, obvious that certain cane varieties may be able to escape infection in spite of the presence of red rot inoculum, in plenty, all around them in irrigation water.

(*d*) Colletotrichum falcatum *Spores produced on leaves and canes*

During the rainy weather, *C. falcatum* midrib lesions are produced frequently on cane leaves and these bear numerous *Colletotrichum* acervuli with abundant spores. Varieties Co. 356, 421, 556, CoS 5, CoK 26 and CoK 32 are particularly known for the profuse production of such lesions on the leaves. Ratoon crop in red rot affected fields, or plants growing from affected setts, produce midrib lesions, with typical *Colletotrihcum* acervuli, very early in the season. Midrib lesions of a different type (Plate XXII, fig. 2), besides the common ones, similar to those described by Chona and Padwick [1942], were also observed on the central spindle in the ratoon crops of red rot affected fields and in the soil and sett-infection experiments with *C. falcatum* (isolate 78). *Colletotrichum* spores in such lesions can act as source of red rot inoculum. The intensity and abundance of leaf midrib lesions appear to have little relation with the resistance or susceptibility of a cane variety. Co. 356, which has been known to be resistant to red rot, produces such lesions in abundance; while Co. 213 which is highly susceptible to red rot, produces comparatively much fewer lesions. Similar results are reported by Abbot [1938]. It is likely, therefore that a resistant variety with profuse production of midrib lesions may serve as a source of infection to susceptible cane varieties grown in the neighbouring fields. In the case of cane varieties highly susceptible to red rot e.g. Co. 213, 223, 299, 373, 556 midrib lesions have been noticed

to pass down from the midrib to the leaf-sheath ; but no case of direct infection from affected leaf-sheath to the cane stalk has so far been observed.

In the advanced stages of red rot infection, when the shoots dry up, the acervuli break through the rind (Plate XXII, fig. 3) and produce innumerable *C. falcatum* spores, particularly on the nodal regions and on the upper, tender internodes, enclosed within the leaf-sheath, often covering their entire surface. In the ratoon crop of red rot affected fields and the plant-crop growing from diseased setts, the shoots start drying up very early in the season and produce *C. falcatum* spores on them, in great abundance, by the end of June or beginning of July ; thus synchronizing with the heavy seasonal downpours of rain, which carry the spores from one field to another and act as a source of red rot infection.

(*e*) *Alternate host*

Appreciation of the role of alternate and collateral hosts is of fundamental importance in the study of the spread and perpetuation of the disease. The only species of *Colletotrichum* found widely distributed in India is *C. lineola* Corda which is known to attack the leaves of *jowar* (*Sorghum vulgare* Pers.). *C. falcatum* and *C. lineola* are indistinguishable as far as their cultural characters are concerned, but according to Butler and Hafiz Khan [1913] and Edgerton [1911] the *jowar Colletotrichum* does not attack sugarcane. Abbot [1938] on the other hand has shown that *Colletotrichum* from midrib lesions of Johnson grass (*Sorghum halepense* Pers.) as well as *jowar* are identical with *C. falcatum* and successfully infected the canes, producing typical red rot symptoms. In preliminary trials at Delhi, Karnal and Pusa no successful infection was, however, produced on *jowar* and maize plants or leaves, inoculated with *C. falcatum ;* whereas the cane plants and leaves, inoculated simultaneously, produced typical red rot infection of canes and leaf midrib lesions. *Colletotrichum* obtained from *jowar* midrib leaf spots when inoculated into the cane leaves or stalks failed to produce any infection. This aspect of the question, however, requires further investigation.

Modes of infection

Regarding the modes of infection of the red rot fungus, Butler [1906], Barber [1901, 1906], Butler and Hafiz Khan [1913] and Kulkarni [1911] in India, from their study of rot of sugarcane, came to the conclusion that the diseased setts are the main source of infection, that the disease passes freely from the diseased mother setts to the shoots, and that the borers do not play any important role in the origin of red rot infection in the cane ; whereas the workers in the Western Hemisphere e.g. Lewton Brain [1908], Edgerton [1910, 1911], South and Dunlop, as reported in an annonymous report from the West Indies [1913], Abbot [1938], Wiehe [1944] arrived at exactly opposite conclusions from their observations and results. The observations made during the recent red rot epidemic in India clearly revealed that this wide spread epidemic could not be ascribed to the use of diseased cane setts alone. Considerable secondary infection of the middle and upper portion of the canes, in the entire absence of any basal infection, was observed in the epidemic areas.

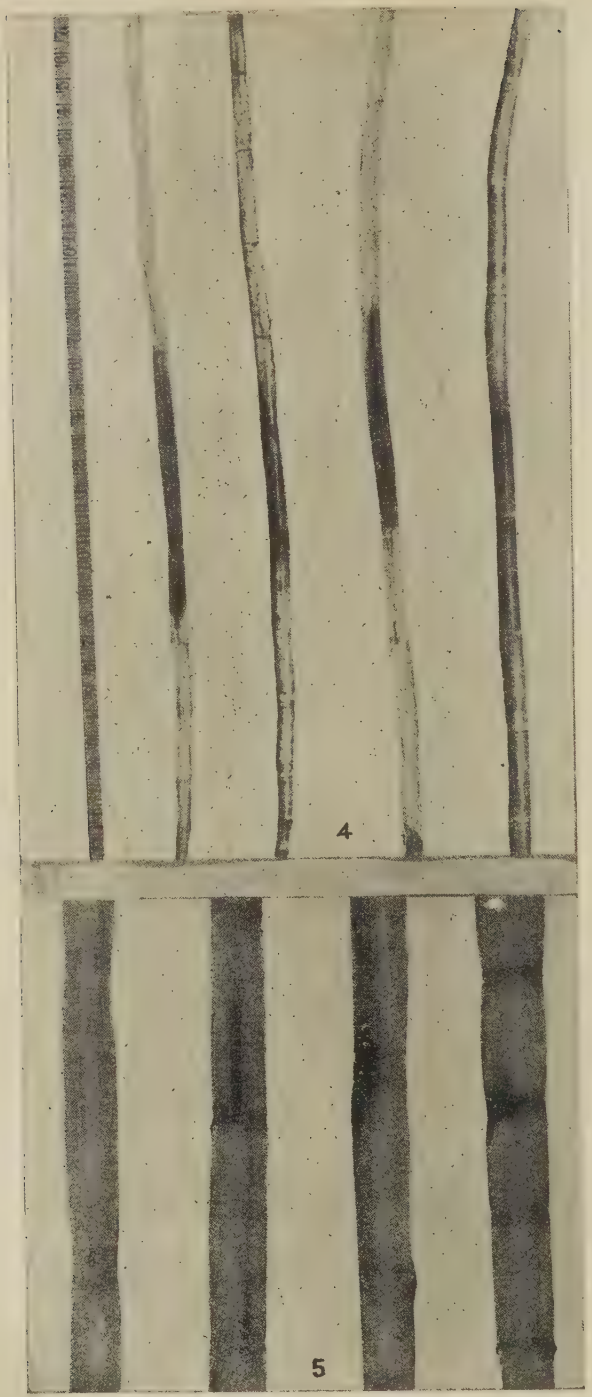

FIG. 1. Co. 299 canes, inoculated at the nodes with *C. falcatum* (isolate 78) showing infection through nodal region

FIG. 2. Canes, inoculated at the nodes with *C. falcatum* (isolate 78) showing various stages of nodal infection

Suitable experiments were carried out, during 1940-45 to study the various possibilities regarding the mode of entry of the red rot organism into the canes, namely, from mother sett to the new shoots ; through root primordia and leaf scars (i.e. the nodal regions) through borer holes ; through cut ends of the setts ; through natural growth cracks in the cane rind etc. The experiments conducted are described below.

(*a*) *Diseased mother sett*

Heavy red rot infection resulting from the use of red rot affected setts as seed material has already been described in the foregoing pages. In these experiments the course of infection passing from the mother setts to the daughter shoots could invariably be tracted with certainty.

(*b*) *Nodal region of canes* : *young nodes*

It has already been stated that considerable infection through the nodal regions of the cane was observed in the epidemic areas of the United Provinces and Bihar. Such infection were also observed in the experiments described above for infection through irrigation watér. In order to study this mode of infection more thoroughly, 50 standing canes of each of the nine varieties, Co. 213, 223, 299, 312, 313, 331, 356, 419, and 421, growing at Karnal, were inoculated (November 1941) at the young nodes, still enclosed within the leaf-sheaths, by pouring few drops of *C. falcatum* (isolate 78) spore suspension in the cavity formed between the receding leaf-sheaths and the cane. In the case of the uppermost two or three internodes it was found necessary to gently pull out the leaf-sheath for the drop of inoculum to travel down to the nodal region. Four to five nodes, on an average, were inoculated in each cane. In the case of controls a few drops of plain water instead of spore suspension were given. The inoculum was repeated on the fifth day after the inoculation. The inoculated plants were sprayed frequently with water for 48 hours following their inoculation. The plots were then irrigated liberally. The experiment was allowed to run for six months, i.e. till the end of April 1942, when all the inoculated canes were carefully examined for red rot infection, by gently scraping the rind of the inoculated nodes. Co. 213, 223, 299 and 331 showed very heavy infection : the incidence on cane basis, being 61, 62, 78 and 44 per cent, respectively and the infection had progressed considerably in the canes. The amount of infection obtained in Co. 312, and 313 was distinctly less, and Co. 419 failed to develop infection. No case of red rot infection was observed in the controls. Plate XXIII, figs. 1 and 2 show a few typical cases of red rot infection of the canes inoculated at the nodal regions with *C. falcatum* (isolate 78), and the various stages of nodal infection.

A similar experiment was conducted simultaneously in the adjoining plot, with Co. 213, 299, 331, 419 and 445, except one difference i.e. the inoculum used consisted of a dark type isolate (*C. falcatum*, isolate 3). No case of red rot infection was observed in any of the five cane varieties.

In another experiment at Karnal, during 1941, 30 canes each of K. 1216 and surkha saharanpuri, a thick ponda cane variety of *Saccharum officinarum* type,

were inoculated in similar manner, with *C. falcatum* (isolate 78). Very severe infection developed in both the varieties. In surkha saharanpuri, the infection travelled even to the underground stubble and from there passed into the uninoculated canes of the clump.

The experiment was also conducted at Delhi with Co. 213, 299, 312, 313, 331 and 419, using *C. falcatum* (isolate 78) as the inoculum. Inoculations were made towards the end of October, 1942. In the beginning of December i.e. about six weeks after the inoculations, two inoculated canes of each of the variety were cut and examined. Only in Co. 299 traces of red rot infection were observed. At the final observations in March 1943, all the inoculated canes were cut and examined for red rot infection and it was found that Co. 213, 299 and 331 showed much greater infection than Co. 312 and 313. The actual incidence of infection obtained was 53, 46, 7, 16, 84, and 22 per cent respectively in Co. 213, 299, 312, 313, 331 and 419.

The experiment was repeated during 1942-43. Healthy canes of ten selected varieties, including Co. 213, 233, 299 and 331, were inoculated at the nodal regions with *C. falcatum* (isolate 78) during August, October and November, 1942. By the end of the season (March 1943), considerable red rot infection was observed in the inoculated canes of all the three series. August inoculations, however, gave the greatest infection ; the exact figures being 76, 100, 100, 33, 80, 30, 67, 35: 35, 14, 57 and 20 per cent for August, October and November series for Co. 213, 223, 299 and 331 respectively. The remaining six canes varieties, under test, showed a great deal of difference in their infection. The controls remained healthy. In nature, the greatest amount of *C. falcatum* inoculum is produced during the rainy weather i.e. June to September.

Old nodes

These experiments were conducted both at Delhi and Karnal during 1941-42. They were essentially similar to those described for young nodes and were carried out at the same time with the only difference that the older nodes on the lower portion of the canes, from which the leaf-sheaths had fallen off and were lying exposed, were inoculated instead of the young nodes. A small swab of cotton wool soaked in spore suspension of *C. falcatum* (isolate 78 or 3) was placed round the nodal region, including the old eyes, and another larger moist swab of cotton wool was placed on the smaller swab and tied with string to keep it in position. The controls were treated in exactly the same way except that no inoculum of the fungus was given. The inoculations were made with both the light (isolate 78) and dark (isolate 3) type of *C. falcatum* at Karnal and only with light type (isolate 78) at Delhi. On an average, about three nodes were inoculated in each cane. Successful infection was obtained at both the places and the results were similar to those obtained in the infection experiments with young nodes i.e. the varieties Co. 213, 223, 299 and 331 developed much greater infection than Co. 312 and 313 ; and that the light *C. falcatum* (isolate 78) proved much more virulent than the dark type (isolate 3). The amount of infection obtained at Karnal, however, was greater than that at Delhi. No case of red rot infection was observed in any of the controls.

The data of these experiments on infection through the nodal region, carried out at Delhi and Karnal; with *C. falcatum* isolates 78 and 3 during 1941-42 and 1942-43 are presented in Table V. Careful examination of nodal infection cases in initial stages, clearly revealed that the infection takes place chiefly through leaf scar, root-primordia and the growth ring; but very seldom through the eye-buds.

TABLE V

Red rot infection through the nodal region of canes with C. falcatum *(isolates 78 and 3) at Karnal and Delhi*

Locality, cane variety and inoculum	Young nodes			Old nodes		
	Number of inoculated canes examined	Number showing red rot infection	Per cent of infection	Number of inoculated canes examined	Number showing red rot infection	Per cent of infection
Karnal: *C. falcatum* (78)—						
Co. 213	41	25	61	50	21	42
Co. 223	45	28	62	34	17	51
Co. 299	46	36	78	49	33	65
Co. 312	43	6	14	46	9	19
Co. 313	53	9	17	46	6	13
Co. 331	36	16	44	42	14	33
Co. 419	29	0	0	48	0	0
Co. 421	52	22	42	42	7	16
Co. 445	35	4	11	41	18	45
K. 1216	31	30	97	30	26	87
Surkha Saharanpuri *C. falcatum* (3)—	24		100	—	—	—
Co. 213	50	0	0	29	0	0
Co. 223	50	0	0	—	—	—
Co. 299	29	0	0	33	0	0
Co. 331	50	0	0	14	0	0
Co. 419	—	—	—	23	0	0
Co. 445	—	—	—	40	0	0
Delhi: *C. falcatum* (78)—						
Co. 213	79	42	53	63	12	19
Co. 299	39	18	46	47	6	12·5
Co. 312	55	4	7	59	0	0
Co. 313	62	10	16	71	3	4·3
Co. 331	32	27	84	42	5	12
Co. 419	13	4	22	53	2	3·9

N.B.—(—) denotes not tested.

From the above data it is clear that considerable red rot infection can take place through the nodal regions of the cane. The possibility of this type of infection occurring in nature is very great. The *C. falcatum* mid-rib lesions, which are so abundant during the rainy weather, produce enormous amount of spores which are washed down with rain or excessive dew from the leaves to the leaf--sheaths and thence to the young nodes and thus bring about infection of the cane. Some of the spores, produced in the mid-rib lesions, are washed down to the ground and are carried about in the field with irrigation water, or rain water during the monsoon, and come into contact with the old nodes on the basal portion of the cane near the ground level, where they may cause infection. Both these types of infection were observed in large numbers in the epidemic tract, and also in the experiments, reported in the foregoing pages, relating to red rot infection through irrigation water containing spores of the causal organism.

Certain cane varieties, like Co. 213, 223, 299, 331, which have been found to offer little resistance to this mode of infection, are likely to suffer greater injury while varieties, like Co. 313, 419 and 421, which have shown comparatively greater resistance, would remain fairly free from disease even if growing amidst plenty of red rot inoculum around them. Such has been the actual experience in the red rot epidemic tracts of the United Provinces and Bihar. Resistance to nodal infection appears to be the most important feature in the field resistance of a cane variety. This method is therefore being used in testing a large number of varieties for their resistance to the disease.

Another point that has been brought out by these experiments is that all the *C. falcatum* isolates do not posses the power to effect nodal infection. C. *falcatum* (isolate 3), a dark type, failed to produce any nodal infection even in highly susceptible varieties, like Co. 213, 223 and 299. Mid-rib leaf lesions of C. *falcatum* are to be found in abundance even in the tracts where there is no red rot. Obviously there is plenty of *C. falcatum* inoculum. The absence of the disease may be due the fact that the *Colletotrichum* flora prevalent may be of such an isolate that has little virulence for nodal infection. A large number of isolations were attempted, during 1942-43, from cane mid-rib leaf lesions from Karnal, Delhi and Shahjahanpur, localities outside the epidemic tract. Only in 35 cases *C. falcatum* could be definitely established, all of which were found to be of dark sparsely sporing type, i.e. possessing characters typical of *C. falcatum* (isolate 3). This presumably explains the absence of any appreciable red rot infection of cane stalks in these three localities in spite of the presence, in fair abundance, of *C. falcatum* inoculum.

(*c*) *Cut-ends of setts.* In these experiments the cut-ends of the setts were dipped in *C. falcatum* (isolate 78) spore suspension for half an hour each. The depth of the suspension, in the container, was about half an inch so that it had no chance to infect the nodes. The treated setts were then surface sterilized, except on the cut-ends, by wiping with rectified spirit, and planted. Observations were recorded regarding their germination and red rot development in the resulting crop. The controls were treated in exactly the same manner with the only difference that the cut-ends were dipped in water instead of the spore suspension. During 1941-42

the experiment was carried out with Co. 213, and 331 at Delhi and with Co. 445, 531, K. 1216, Dehra Dun ponda and surkha saharanpuri at Karnal. About fifty 3-eye setts of each variety were treated with *C. falcatum* (isolate 78) spore suspension in April 1941 and planted in the field. All these varieties are known to be highly susceptible to red rot. Germination was rather poor in most of the varieties, the planted setts having been severely affected with red rot attack. Surkha saharanpuri and Dehra Dun ponda, the two *S. officinarum* type cane varieties, and Co. 531 completely failed to establish any clumps. By the end of the season (March 1942), Co. 213 and 331, at Delhi, showed 54 and 15 per cent red rot infection respectively in the resulting crop. A few cases of infection were observed even earlier in the season *i.e.* during August and September, 1941. Co. 445 and K. 1216, at Karnal, developed 5·7 and 6·8 per cent infection respectively.

The experiment was repeated during 1943-44 at Karnal with Co. 213, 223, 299 and 331. Red rot infection obtained in these four varieties was 64, 37, 82 and 45 per cent respectively; thus clearly indicating the possibility of red rot infection occurring through the cut ends of the setts planted.

(*d*) *Through the naturally occurring growth cracks in the cane rind.* Of the nine such cane varieties that generally show growth cracks in the internodes, namely Co. 223, 312, 396, 411, 548, COK 10, B.O. 4, Co. S. 76, K. 1216, inoculated at the cracks with *C. falcatum* (isolate 78), Co. 223, developed 6·6 per cent infection; Co. 396, 548 and B. O. 4 gave 18-22 per cent infection, while the remaining five varieties failed to develop red rot infection.

(*e*) *Through the borer holes.* During the extensive red rot observations in the epidemic areas, for three seasons, the role of borers was also studied. It was found that though in a few canes both red rot and borer attack was present, in by far a larger number of cases there was red rot attack without any evidence of borer injury. Furthermore there were several cases where there was definite borer attack but no red rot infection, thus indicating that borers play little part in starting or spreading the red rot disease.

Besides these general observations regarding the association of borers with red rot, special attention was paid, while taking the final observations of the carefully controlled soil infection and other experiments, reported in previous pages, to note the borer injury in all the experiments. It was found that some of the canes that took infection showed borer injury near the ground level or in the under-ground portion of the cane stalk, from where the infection would have possibly started but in a very much larger number of canes, that developed infection, no trace of borer attack could be observed. Furthermore, there were canes in these experimental plots that had failed to take red rot infection inspite of presence, in abundance, of *C. falcatum* inoculum during the various stages of growth of these canes. Many of these showed distinct borer attack. Even in the cases where both red rot and borer holes were present, the origin of red rot infection could not always be traced to the borer holes. Data regarding some of these observations are set out in Table VI.

TABLE VI

Red rot infection and borer attack in certain soil and irrigation water-infection experiments at Karnal during 1941-42

Cane variety	Total number of canes examined	Number affected with red rot	Number of affected canes showing borer attack	Number of healthy canes	Number of healthy canes showing borer attack
(a) *Soil infection with red rot affected cane debris*					
Co. 213	239	68	15	171	51
Co. 223	241	64	36	177	118
Co. 299	113	39	5	74	15
(b) *Soil infection with* C. falcatum (*isolate 78*)					
Co. 213	163	53	19	110	50
Co. 223	147	15	10	132	66
Co. 299	104	77	31	27	9
(c) *Red rot infection with irrigation water* (C. falcatum, *isolate 78*)					
Co. 213	98	54	28	44	20
Co. 223	294	82	52	212	0
Co. 299	40	32	22	8	0

Similar results were obtained in the soil infection experiments carried out at Delhi during 1941-42. Observations regarding the association of borers with red rot were again made during the 1942-43 season soil-infection experiments at Delhi and Karnal. Results obtained were similar to those of the previous season. Owing to heavy red rot infection of the cane crop in experimental plots from early in the season till harvest time it may be safely assumed that red rot inoculum was present, in plenty, throughout the season.

These observations clearly point to the fact that borers play no important part in bringing about red rot infection or spreading the disease under the conditions obtaining at Delhi or Karnal. The field observations on this point, in the epidemic areas, reported in the foregoing pages, also support this view. Furthermore several attempts made, from time to time, to isolate *C. falcatum* from the borer tunnels in the cane resulted, generally, in failure. These results thus confirm Butler's

findings regarding the role of borers and red rot in India. In nature, borers are the chief source of producing wounds in the cane rind. Further investigations are necessary to find an explanation as to why red rot infection through the borer holes does not take place. Any injury to the cane rind should mean an easy entry of *C. falcatum* into the cane tissue and thence to start the red rot attack.

Discussion

Soil infection experiments have clearly proved that considerable red rot can occur through soil infected with red rot cane debris or the spores and mycelium of the fungus, even if healthy setts are planted. We have to, therefore, change our conventional views of ' clean setts and no red rot '. The farmer must have a clean field as well as clean seed. The dried up red rot canes, which are usually left over during the harvesting of the crop, must be removed from the field and destroyed so that they cannot act as a source of infection to the next cane crop in the adjoining or nearby fields. It is fortunate that the survival of red rot infection in the soil is limited to only 5 to 6 months, but we should not feel unduly complacent over it as there is every possibility of the soil getting repeatedly infected owing to the existing cultural practices of cane cultivation ; thus resulting in perpetual red rot infection in the soil.

Even a healthy crop, grown in a healthy field, from healthy seed, can become infected with red rot later in the season through irrigation water containing C. *falcatum* spores. The infection takes place through the nodal regions of the cane near the ground level. The disease incidence brought about is greater if the infection with irrigation water takes place during the months of July or August. The possibility for such an occurrence is great. In nature, *C. falcatum* spores are produced in great abundance on leaf mid-rib infections by July or August and even slightly earlier on the shoots of red rot affected ratoon clumps or even plant-cane clumps that may have contracted red rot infection at the time of planting or soon after. During these very months, mass movements of water usually take place in nature, owing to heavy downpours of rain, when water flows freely from one field to another and thus carry red rot inoculum from diseased fields to healthy ones.

C. falcatum leaf lesions are found to occur, in plenty, even in areas where there was no appreciable red rot infection, e.g., Shahjahanpur, Delhi, Karnal, etc. Several isolations made from leaf mid-rib lesions from these localities yielded a dark type, weakly parasitic, *C. falcatum*. The absence of red rot infection in the cane crop in these areas could, reasonably, be ascribed to this fact.

As regards the modes of infection, the persent experiments have confirmed Butler's view that the disease is carried over through diseased setts. Infection lesions were often observed passing from the diseased mother sett to new shoots in Co. 213, 223, 299 and 331. However, great deal of differences were observed in this mode of infection in the ten cane varieties tested, which is possibly due to their greatly varying degree of resistance to red rot. Co. 313, 356 and 421 gave very low infection in sett-infection experiments usually. These varieties are well known for their resistance to the disease.

The observations in the red rot epidemic areas and the soil infection experiments at Delhi and Karnal regarding association of borers with red rot have clearly shown that borers play little part in originating the disease or its subsequent spread. These findings support Butler's views and are opposed to those of Lewton Braine [1908] Edgerton [1911] Wiehe [1944] and Abbot [1938]. Orian [1946] has also recently reported that the large proportion of attack of red rot could not be correlated with insect injury in Mauritius.

Red rot infection through the nodal regions of the cane, similar to the one described by Abbot in Louisiana and Florida, was observed to occur in the epidemic affected areas in Northern India. It is, however, not so restricted as considered by Abbot [1938], as several cane varieties were found to show this type of infection in the epidemic areas of Eastern United Provinces and Northern Bihar. In the experiments, reported above, of the eleven cane varieties tested as many as nine were found to develop considerable red rot infection through the nodal region. In another experiment (not reported above) with 96 cane varieties for red rot infection through the nodal regions of the cane, 33 showed more than 25 per cent successful nodal infection of the inoculated canes. Highly susceptible varieties, like Co. 213, 223, 299 showed 100 per cent nodal infection.

The possibility of such infections occurring in nature is great; *C. falcatum* spores produced in the leaf mid-rib lesions, get washed down with rain, or excessive dew, into the cavity between the cane and the leaf-sheath and thus reach the nodes and cause infection. The young nodes, on the upper and middle portion of cane, have been found to be comparatively more vulnerable to nodal infection than the older ones below. Great differences were also observed in different cane varieties in their susceptibility to this mode of infection. The varieties which possess a comparatively greater resistance to nodal infection are likely to remain free from disease even if growing with plenty of red rot inoculum about them. Such has been the actual experience in the red rot epidemic affected tracts in the United Provinces and Bihar; Co. 313, Co. 356, Co. 421, etc., which have shown appreciable resistance to nodal infection, were observed to have remained almost free from red rot during the 1938 to 1940 epidemic even in the worst affected fields. Furthermore, it has also been shown that this power of nodal infection is not possessed by all the isolates of *C. falcatum*. Evidently the predominance of only such isolates that possess this power could cause any appreciable secondary infection of the cane crop and bring about an epidemic.

Nodal infection, therefore, could be used as an important test to determine the pathogenic power of the prevailing *C. falcatum* flora of any particular tract and the resistance of the various cane varieties grown therein to be able to predict the possibility of an outbreak of red rot epidemic.

Red rot infection taking place through the cut-ends of the setts under field conditions has been clearly demonstrated. These results are at variance with those reported by Abbot [1938], who considers that, though in laboratory tests infection of setts is possible through cut-ends of the setts, this mode of infection is of little

practical importance. The explanation put forth being that the ends of seed cuttings soon become overgrown with yeasts and other organisms, or they ferment, both of which serve to prevent the growth of the red rot fungus. May be, the different results obtained are due to the differences in the method of infecting the cut-ends of the setts; while Abbot applied the inoculum in the form of an agar culture, spore suspension was used in the present investigation for infecting the cut-ends. The spores may have thus got a chance to get lodged in the interior of the sett and avoid antagonism of soil microflora.

It has also been shown that red rot infection of growing canes can take place through the growth cracks in the cane rind. The *C. falcatum* leaf mid-rib lesions, it would be evident, are responsible, to a great extent, in the production and dissemination of the red rot inoculum; and that in certain varieties these lesions are more numerous and extensive.

Summary

The importance of red rot as a major disease of sugarcane in Northern India cane tract is indicated.

The occurrence of considerable secondary infection observed in the red rot epidemic area is briefly described which indicated that our earlier views of 'clean setts and no red rot' needed revision.

Various possible sources of infection and modes of infection of red rot have been studied and the results obtained have clearly proved the following points:

(*a*) that considerable red rot infection can take place through soil infected with red rot affected cane debris or the spores and mycelium of the fungus, even when healthy setts are planted. The farmer, therefore, should have a 'clean field' besides 'clean seed';

(*b*) that even a healthy crop, grown in a healthy field from healthy seed, can develop considerable red rot infection through irrigation water containing *C. falcatum* spores; and that disease incidence is much greater if the infection with irrigation water takes place during July or August. The possibility for such an occurrence in nature is great. The infection took place in all these cases through the nodal regions of canes;

(*c*) that the setts inoculated with *C. falcatum*, or from diseased canes, give poor germination and heavy red rot infection in the resulting crop; and that disease lesions passing from diseased mother setts to the new shoots have often been observed;

(*d*) that the observations made on the association of borers with red rot have shown that borers play little part in starting the red rot infection in cane or its spread in the crop;

(*e*) that considerable red rot infection can occur through the nodal regions of the cane; and that the upper, younger nodes of the cane are more

susceptible than the older, basal ones. The possibility of such an infection occurring in nature is great, is clearly indicated;

(*f*) that the red rot infection can take place through the cut-ends of the setts;

(*g*) that red rot infection can occur through the growth cracks that occur in nature, in the cane rind;

(*h*) that there are clear indications of great deal of differences in different cane varieties in their resistance to red rot infection through soil, through setts and through the nodal regions;

(*i*) that in the various comparative tests, in soil, sett- and nodal-infection experiments, the light type, freely sporing, *C. falcatum* (isolate 78) always proved more virulent than the dark type; sparsely sporing, *C. falcatum* (isolate 3); and that isolate 29 proved to be intermediate between the two. Also that all the *C. falcatum* isolates do not possess the power to infect the cane through the nodal region, which explains the absence of red rot, to any appreciable extent, in various localities in spite of the presence of *C. falcatum* inoculum in fair abundance; and

(*j*) that *C. falcatum* leaf mid-rib lesions and spores produced on shoots of red rot affected ratoon clumps constitute an important source of red rot inoculum and its dissemination.

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THE EPIDERMAL CHARACTERS OF SUGARCANE LEAF IN RELATION TO INSECT PESTS

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(With Plates XXIV—XXV)

THE epidermal layer of plants affords protection to the enclosed tissues. The various modifications of the epidermal cells into spines, hairs, etc. have been found to be capable of meeting the adverse effects of certain environmental factors especially insect pests. These modifications which differ with the different varieties of sugarcane along with other structural characters offer differing resistance to pests and diseases.

The veins in sugarcane leaf are prominent and run parallel to the midrib along the length of the lamina and divide the leaf surface and midrib into ridges and grooves. The ridges have under-lying them the hard sclerenchymatous tissue surrounding vascular bundles and the grooves occupy the intermediate space between the ridges. The epidermis of sugarcane leaf and midrib has long epidermal cells, short cell groups (comprising of cork cell and silica cell) interposed between the long cells and short bulbous spines (denticules) on the ridges, while the stomata occupy the grooves where the epidermis has comparatively lesser number of short cell groups and an occasional denticule here and there, if any. The denticules are bulbous (Plates XXIV—XXV) and have short pointed protuberances like spear-heads pointing towards the apex of the leaf. These are so arranged in regular rows on the ridges, as to offer considerable hinderance in the crawling movement of larvæ on the sugarcane leaf. Different varieties of sugarcane differ in the occurrence of the denticules per unit length. It has been the purpose of this investigation to find out the extent of protection these denticules offer against pests on the leaves of some of the common sugarcane varieties, a knowledge of which will also be useful in the selection of suitable varieties from the promising seedlings.

One of the important pests of sugarcane leaf is top-borer (*Scirpophaga nivella F.*) which attacks many varieties of sugarcane and in some cases the incidence of attack may be as severe as 80 per cent. The attacked plants are characterised by ' bunchy tops ' resulting in stoppage of growth and consequently cause considerable loss to the sugarcane growers.

The top-borer lays its eggs on the lower side of the leaves. The larva which is actively moving about when newly hatched, on reaching a suitable host, moves to a newly opening leaf and punctures at the basal portion of the leaf through the lower midrib. According to Rao [1947] the larva has to bite through seven to eight vascular bundles of the outer row in the midrib, in tunneling its way to the growing point of the Sugarcane. Hence varieties having greater lignification in the midrib are more resistant to top-borer.

Issac [1939] observed that sugarcane varieties, with hard midrib, were more resistant to top-borer attack than those with soft midrib. This view has been supported by Venkatraman and Rao [1941], and as a possible explanation the hardness has been ascribed to the extent of development of the lignified tissue round vascular bundles and the sclerenchymatous columns found on the lower side of the midrib. Rao [1947] has opined that the number of bristles on the epidermis has no correlation with the resistance of sugarcane varieties to top-borer.

The data collected in connection with top-borer infestation at this Research Station support the view that a sugarcane variety possessing on its midrib a greater number of denticules is less susceptible to the attack of this pest.

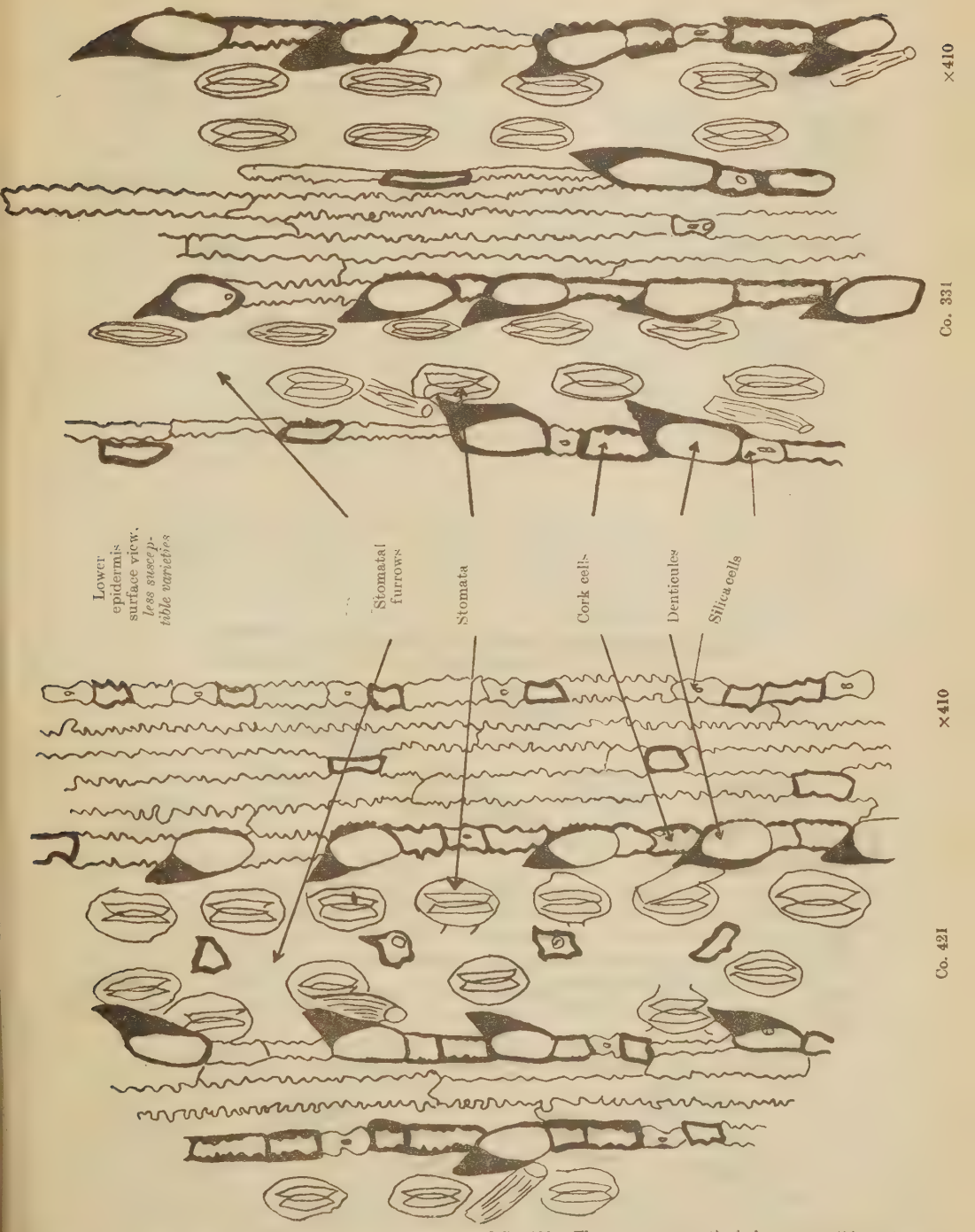
The efficiency of the protective armour on the midribs of different sugarcane varieties can suitably be measured by determining on an average, number of denticules per unit length of the groove margin. The midribs of a number of first fully opened leaves from some of the common sugarcane varieties at three inches from the junction of the leaf—sheath and lamina were taken for comparison and epidermal peelings were obtained by macerating them. The averages for the number of denticules and the total number of epidermal cells (including the special cells) have been worked out and shown in Table I. The varieties may also differ in the length of epidermal cells and therefore for comparison it has been considered desirable to find out the number of denticules per cent epidermal cells per unit length.

TABLE I

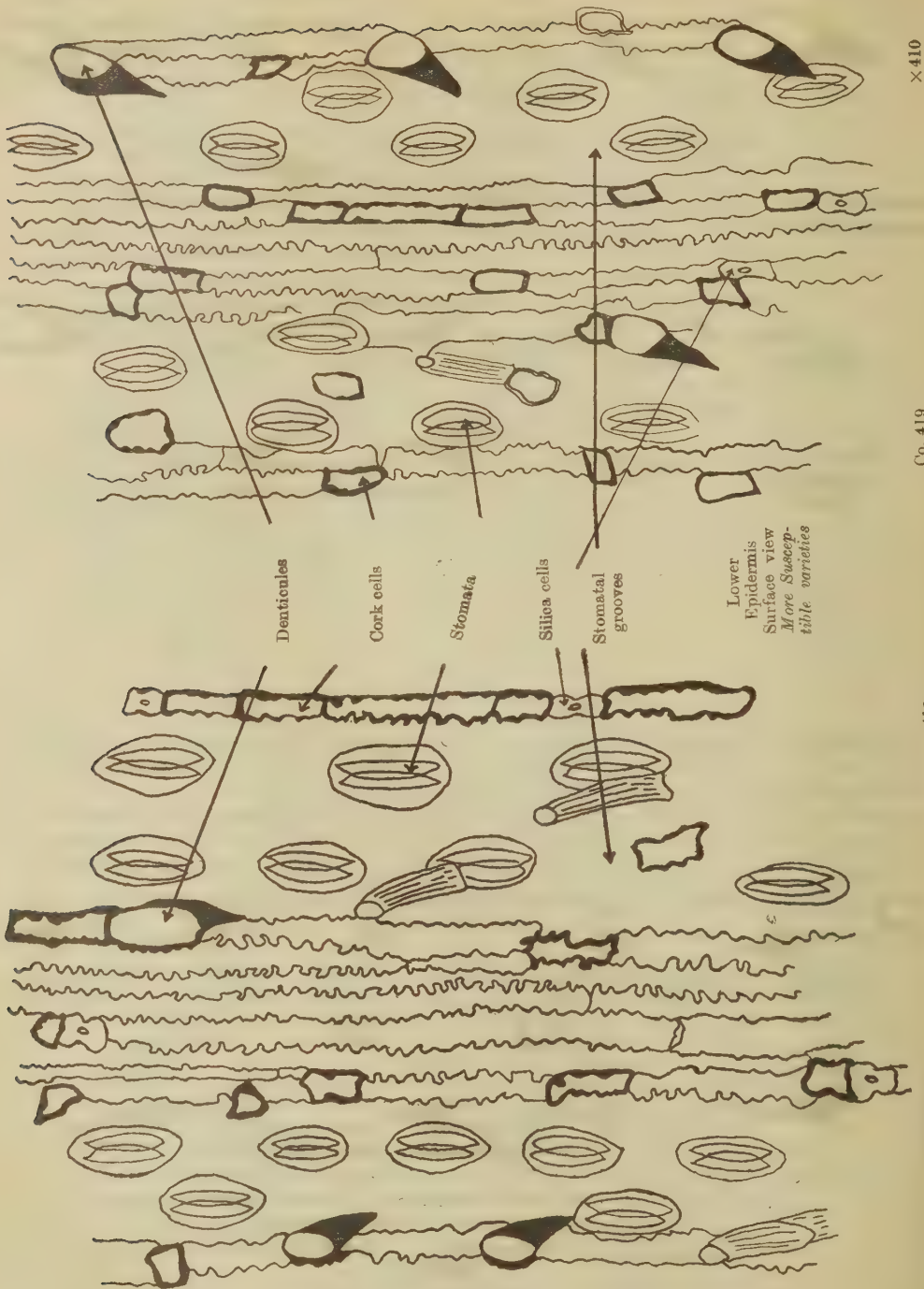
The protective mechanism of leaf midribs against top-borer attack

Varieties	Denticules per 1 mm. length	Epidermal cells per 1 mm. length	Denticules per cent epidermal cells per unit length	Nature of resistance to top—borer
Co.331	10	28	35·7	Less susceptible
Co.421	11	35	31·4	do.
Co.K.28	12	35	34·2	do.
Co.S.186	11	31	35·4	do.
Co.527	4	27	14·8	More susceptible
Co.419	3	23	13·0	do.
Co.312	1	21	4·7	do.

It will be seen from the Table I that the less susceptible varieties show a higher percentage of denticules than the more susceptible varieties. The denticule tips



Surface view of the dorsal epidermis of the midrib of Co. 331 and Co. 421. These are comparatively less susceptible varieties to top-borer attack



Surface view of the dorsal epidermis of Co.312 and Co.419. These are comparatively more susceptible varieties to the top-borer attack

are so directed, towards the apex of the leaf and the centre of the groove, as to be sufficiently deterrent for small larvæ to crawl over the epidermis. In order to tunnel its way down, the larva must bite through seven to eight vascular bundles as well as the overlying denticules. While greater lignification possibly gives greater strength to the midrib, a greater population of denticules on its epidermis offers greater hinderance in the movement and biting process of the larvæ and thus adds greater efficiency to the protective mechanism. The (Plates XXIV and XXV show the surface view of the epidermis of less susceptible and more susceptible varieties. The marked contrast in the number of denticules is clearly seen.

Summary

Rao [1947] has shown that sugarcane varieties having greater amount of lignification in the midrib are more resistant to top-borer attack. An investigation into the number of denticules on the lower surface of midribs of a number of sugarcane varieties has been carried out. The results indicate that a greater population of denticules on the midribs adds greater efficiency to the protective mechanism of sugarcane leaves against the attack of top-borer.

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PHYTOPHTHORA PARASITICA ON FRENCH BEAN *PHASEOLUS VULGARIS* LINN.

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(With Plates XXVI—XXVII)

French bean, *Phaseolus vulgaris* Linn. is extensively cultivated round about Bangalore. In August 1945 and October 1946 the crop in lowlying fields was found infected. There are several reports of the occurrence of *Phytophthora phaseoli* Thaxt. on Lima bean (*Phaseolus lunatus* Linn.). Tucker [1933] records the following cases of occurrence of *Phytophthora* spp., on French beans: by Stevenson in Puerto Rico of *P. parasitica* causing a wilting and dying of the tops and a wet rot of the pods, by Youngberg in the Philippines of *P. palmivora*, by Young of successful inoculations on the leaves with *P. cactorum*, by Sawada of positive inoculations on the pods and seedlings with *P. citricola*, by Reddick of a wet rot of Navy pea bean pods inoculated with a tomato strain of *P. parasitica*. A preliminary note on the occurrence of a *Phytophthora* on French bean was read by Venkatakrishnaiya [1946] before the Indian Science Congress in 1946. There appears to be no other record of *Phytophthora* on French bean in India. Therefore, it was thought necessary to determine the exact species of *Phytophthora* responsible for the pod rot.

Symptoms

Infection is noticed on the lower, young, green pods after a heavy rainfall. The pod presents a water-soaked appearance. The fungus grows as a dense, white felt and spreads over the entire surface of the pod in wet weather (Plate XXVI, fig. 4, 5). As the infection advances the pod shrivels up and decays. The mycelium penetrates the tissue of the pod and is found in the seed. The sporangia measure 27·5 to 63.μ×14 to 47·5μ (average 46×28μ). Oospores are observed in the infected tissue of the pod and seed coats, and measure 14 to 23·5μ (average 19·5μ).

Fungus

The fungus makes a dense, white, fluffy, ærial growth on oat and onion agars but not on potato dextrose agar or French bean agar. It grows slowly and thinly on maltin (Merck's) agar. The ærial growth of the mycelium is luxurious on sterilized slabs of potato and French bean pods. Microtome sections, 10μ thick of early infected pods stained with Haidenhain's iron-alum hæmatoxylin and orange

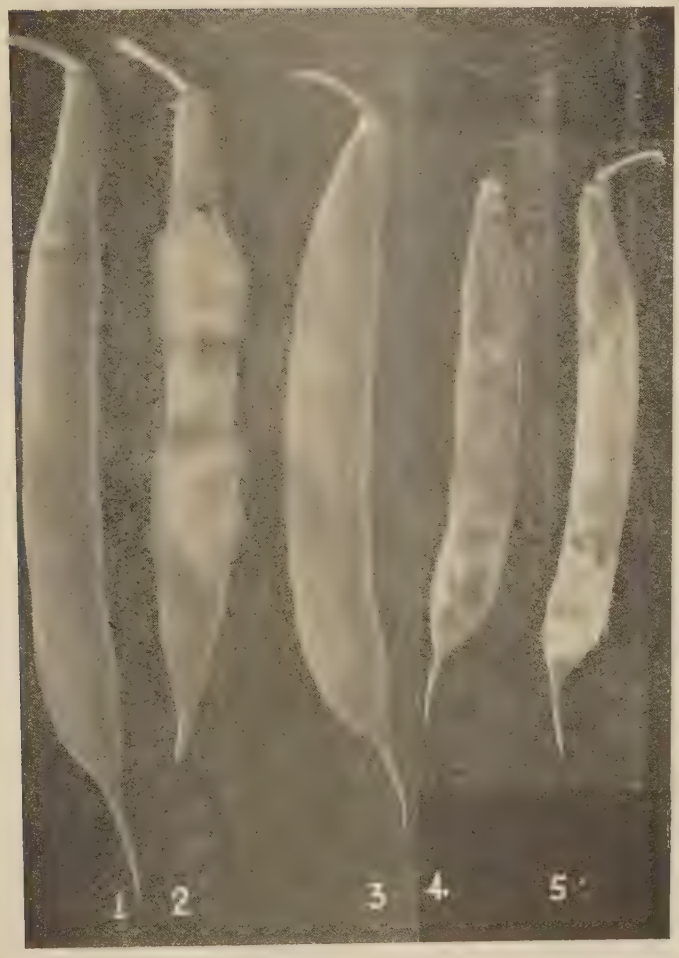
G showed the mycelium to penetrat the epidermal cells and to ramify freely within the tissue of the pod. The mycelium is both intercellular and intracellular.

The antheridium in culture is hyaline and amphigynous. It varies in shape and size from 10 to 20μ×8 to 16μ. The oogonium measures from 23 to 40μ in diameter. The oospores are formed abundantly in culture on oat and French bean agars. They are yellowish to brownish in colour, thick walled, and range from 19·5 to 27·5μ (average 22·5μ). The production of oospores in culture is not regular. They are formed abundantly or not at all even after five months. They were observed in cultures from the infected tissue in September 1945 and in October 1946. They were present in single hyphal tip isolations in September 1947 and not in May 1948. Paired cultures of the French bean fungus were grown with recent transfers of *Phytophthora arecæ*. Oospores were produced in five to six days at the union of the two growths. They averaged 24·5μ in diameter.

Chlamydospores are produced in culture and in the inoculated beans. They are terminal or intercalary, round, possess three smooth walls and have a brownish tinge. They vary from 16 to 43·5μ in diameter (average 30·5μ). Their size corresponds to that of the chlamydospores of *P. parasitica* and *P. arecæ* recorded by Dastur [1912], Rosenbaum [1917], Tucker [1931] and Venkatarayan [1932]. Chlamydospores have not been reported in *Phytophthora phaseoli*.

Inoculations

Inoculations with the fungus were made on injured and uninjured green pods of French bean, on tubers of potato (*Solanum tuberosum* Linn.), carrot (*Daucus carota* Linn.), radish (*Raphanus sativus* Linn.), on unripe and ripe fruits of tomato (*Lycopersicum esculentum*, Mill.), *bhende* (*Hibiscus esculentus* Linn.) and brinjal (*Solanum melongena* Linn.) under aseptic conditions. Infection was observed on the inoculated uninjured French beans and on fruits of tomato and brinjal in about seventy-two hours and on the injured ones in forty-eight to sixty hours (Plate XVI; figs. 1-3, Plate XVII, fig. 2. Infection was turned slow on the injured fruits of *bhende* (Plate XVII, fig. 3.) and on wounded tubers of potato. The inoculated tubers of potato when cut turn slightly pinkish in colour which became brownish after sometime. According to Tucker [1931] this is characteristic of *P. parasitica*. Infection was not observed on uninjured tubers of potato, carrot and radish. The fungus was reisolated from the inoculated French bean pods and found to resemble the original isolation in all respects. The pathogenicity of the fungus was also tried in the laboratory on potted plants of tomato, chilly (*Capsicum annuum* Linn.), castor (*Ricinus communis* Linn.), potato and on small green fruits and grown up castor leaves on twigs standing in water in Erlenmeyer flasks. Infection was observed within twenty-four to forty eight hours on the injured leaves of potato, tomato, castor (Plate XXVII, fig. 1) and on the fruits of chilly and castor but not on the leaves of chilly. The inoculated leaves of potato turned black and began to rot rapidly while infection on the fruits of castor and chilly was slow. The inoculated fruits and hypocotyl of castor turned



FIGS. 1 to 5 photographs of inoculated French beans

„ 1. Uninjured bean showing slow infection

„ 2. Injured bean showing infection

„ 3. Control

„ 4. Naturally infected French bean

„ 5. Healthy pod showing the thick covering of the mycelium when kept mixed with an infected pod

FIG. 1. Castor seedlings ; (A) control and (B) inoculated leaf showing the water soaked spot

„ 2. Brinjal fruit inoculated with the fungus

„ 3. Fruit of *bhende* showing slow infection at the inoculated region X

black. The discolouration extended in both directions on the seedlings which finally died.

Inoculations with the mycelium and zoospores of a recent transfer of *P. arecæ* were tried on injured and uninjured leaves and pods of French bean, leaves and fruits of tomato, chilly, castor and fruits of brinjal. The castor leaves developed the infection in about seventy two hours and the others did not even in four days. The controls remained healthy.

Discussion

Tucker [1931] reports that *P. phaseoli* is restricted in its parasitism and is known only on *Phaseolus lunatus* Linn. It does not grow on malt and potato dextrose agars in six days, makes a meagre growth on ordinary agar media and produces oospores regularly, promptly and abundantly on oat agar. The *Phytophthora* on French bean infects castor and wounded potato tubers. The production of oospores is irregular and uncertain. It produces abundant chlamydospores in culture which is not characteristic of *P. phaseoli*. On the basis of these findings the author believes that the French bean fungus is *P. parasitica*.

Control

The disease is not serious except in rainy weather. Since the infection is mostly on the pods lying close to the soil, the disease can be controlled by picking out early all the infected pods and by spraying the plants thoroughly with a one per cent Bordeaux mixture.

Summary

A *phytophthora* on French bean (*Phaseolus vulgaris* Linn.) was observed for the first time in Bangalore. The fungus was brought into pure culture. Its cultural and morphological characters were studied. Inoculation experiments with the fungus on French bean pods, on the leaves, fruits and seedlings of castor (*Ricinus communis* Linn.), on the leaves and fruits of tomato (*Lycopersicum esculentum* Mill.), on fruits of brinjal (*Solanum melongena* Linn.) and *bhende* (*Hibiscus esculentus* Linn.) and on the leaves and tubers of potato (*Solanum tuberosum* Linn.) were successful while those on the leaves of chilly (*Capsicum annuum* Linn.), on roots of carrot (*Daucus carota* Linn.) and radish (*Raphanus sativus* Linn.) were not successful. The fungus produced abundant chlamydospores in culture and formed oospores irregularly in pure culture but always in paired culture with *P. arecæ*. The antheridia are amphigynous. The fungus agrees generally in morphological, cultural and pathogenic characters with *P. parasitica*. The disease can be controlled by picking out all the infected pods and spraying the plants with Bordeaux mixture of one per cent strength.

Acknowledgment

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REVIEWS

The Theory of Inbreeding

By R. A. Fisher, published by Oliver & Boyd Ltd., 1949 : 120 pp. 10*s*. 6*d*. net.

A BOOK by Prof. R. A. Fisher, it is no exaggeration to say, constitutes a landmark in the progress of science. His ' Statistical Methods for Research Workers ' was a pioneering work which started the era of exact tests of significance. ' The Design of Experiments ' revolutionised the technique of field experimentation in agricultural and biological sciences. The appearance of ' The Genetical Theory of Natural Selection ' was a notable event in the development of genetics. Dr Fisher, now the Arthur Balfour Professor of Genetics at the University of Cambridge, has in his latest work undertaken the elucidation of the theoretical considerations underlying the practice of inbreeding and its genetical consequences.

The book opens with an introduction stressing the importance of a theoretical and practical study of the subject of inbreeding in genetic and agricultural research. Allaying the exaggerated fears of the grave risks attendant on the practice of inbreeding, the author directs attention to ' the great boon of reliability of breeding performance ' which the system offers, and which is so essential for the purposes of pure research and invaluable in the parent material in hybridisation work. The next chapter is devoted to the features and uses of segregating inbred lines. After defining the matings which can be regarded as ' eligible ', the number of progeny required to be bred in each generation in order that at least one eligible mating may be possible is worked out. The third and perhaps the most important chapter deals with the speed with which the breeding material attains progress towards homozygosity when it is subjected to repeated sib-matings. The effect that an irregularity in breeding practice may have on this rate is also evaluated and the extremely interesting consideration of the consequences of maintaining in constant segregation a certain number of loci on the progressive reduction in the heterozygosity of the germplasm as a whole brings the chapter to a fitting climax. In the last chapter various other systems of inbreeding such as parent-offspring matings are briefly considered on lines similar to those adopted in the more detailed discussion of the sib-mating system in the previous chapter. Three appendices attached consist of brief notes. The first deals with the relative merits of different mating systems in inbreeding in the case of species bearing only a single offspring at birth ; the second discusses the efficacy of self-sterility mechanisms among hermaphrodites in avoiding inbreeding, and the third summarises the function of inbreeding in animal and plant improvement.

The book demands for its study a knowledge of elements of probability and of linear equations and of course an understanding of the concepts in genetics. It is written in the inimitable alluring style that distinguishes all the writings of Prof. Fisher and is not only extremely thought-provoking but also makes for lucid and enjoyable reading. (V.N.A.)

Plant and Soil Water Relationships

By Paul J. Kramer, McGraw-Hill Book Company, Inc., First Edition, 1949 $4·50

THE word attention has been focussed, of late, on food grains and their quality, consequent on the prevailing scarcity of food. With this background, researches on plant nutrition have acquired importance more than ever before. Publications like the one under review are, therefore, of great value to workers in the field of plant nutrition. The book under review deals with the relation of the plant with soil water. This aspect of plant physiology is the basis of almost the whole of plant nutrition. The author gives a very interesting and illuminative historical introduction and then proceeds to discuss the various aspects of the problem of plant and soil water relation. He has summarised the findings of previous workers in the field. The interesting aspect of the book is that the author does not thrust his view on the reader although he puts unobtrusively his own interpretation on the data collected by others. There is a full bibliography of 37 pages and the get-up of the book is up to the standard of the well-known publishers. It would be a valuable handbook for the workers in the field of plant and soil water relationship. (P.P.)

Prize for Fruit Preservation

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Messrs. Gardeners Corporation, New Delhi have offered a prize of Rs. 200 per year to the best contributor of an article on 'fruit preservation and canning'. While giving this award they have selected, besides one or two other Journals, the two Journals of the Indian Council of Agricultural Research *viz.*, Indian Journal of Agricultural Science and Indian Farming, out of which, contributors of articles on the subject have to be selected. The award has been given on an annual basis and the first award will be given to the contributor of the best article on the subject during the period 1-1-51 to 31-12-51. To adjudicate articles, a Committee consisting of the following gentlemen has been formed :—

(1) Dr. V. Subrahmanyan, Director, Central Food Technological Research Institute, Mysore,

(2) Dr. Girdhari Lal, Asst. Director (Fruit Technology), Central Food Technological Research Institute, Mysore,

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